Combined exposures of noise and whole-body vibration and the effects on psychological responses, a review

J, K Ljungberg
Department of Work and Science, Division of Engineering Psychology, Luleå University of Technology, SE - 971 87 Luleå, Sweden
jessica.korning-ljungberg@ltu.se

The aim of this review is to shed light on a research area that concerns the studies of psychological responses to combined exposures of noise and whole-body vibration (WBV). Vehicle drivers are a group of workers that are often exposed to multiple stressors like noise, WBV and mental loads. Degraded performance because of environmental stressors may lead to injury or accidents. Standards that govern health risk assessment do not take into consideration the complexities of these multiple exposure environments (ISO 1997a, ISO 1999). Some studies have shown that the effect of one factor may be different than the effect of two factors presented together. For example, negative combined effects have been found in tracking tasks (Sommer and Harris, 1973), in arithmetic tasks (Harris and Schoenberger, 1980), as well as in subjective ratings (Ljungberg, Neely, Lundstrom, 2004), although in many of the studies the noise and WBV stimuli have been very unlike those that can be found in real workmg environments. Applying methods from the "irrelevant sound" paradigm (e.g. Jones, 1990) by using short-term memory tasks with a serial component as well as focus on frequencies rather than level has been revealed to tap the resources both objectively and subjectively more in both noise and WBV studies (e.g. Banbury et al. 2001; Kjellberg, 1990) Still, most experiments that have been conducted have focused on rather short exposure times in controlled laboratory settings. Using longer exposure times might also reveal other results since longer exposure times may be negatively related to sensitivity to noise and WBV (Abbate et al. 2004; Neely, Lundstrom, and Bjorkvist, 2002, Weinstein, 1978)

1. 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 half-day'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, especially those generated by WBV (e.g. Sherwood and Griffin, 1990) If unwanted environmental stimuli physically interfere, overloading a driver's mental capacity may negatively affect performance and may lead to a higher risk of 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).

Although it is fairly common for noise exposure to be the only or most significant 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.

The psychological effects of combined noise and WBV are a rather unknown research area but may deserve some more attention. The aim with this paper is therefore to try to give an overview of what has been done within this topic, but starting with an overview about the results obtained in the research area concerning the effects of single noise and WBV exposure.

2. PSYCHOLOGICAL EFFECTS OF NOISE

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. For example, some studies has found negative effects on cognitive performance in different tasks when participants has been exposed to a continuous free field noise generated between 125-4000 Hz and played at 75, 78 dB(A), and 85 dB(C) (Smith, 1991; Smith and 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 and Miles, 1987), and performance of a task which measures the detection of repeated numbers (Smith, 1988).

Many studies commonly agree today that sounds with a changing character are more disruptive to short-term memory performance than rather predictable sounds (e.g. Banbury et al. 2001). The general focus in these studies has been to examine more varied characteristics of level and frequency in the sounds. The results have been unanimous, there is a disruptive effect on short-term memory performance caused by the unwanted auditory distracters if a sound contains a series of changing spoken items or pure tones which are presented during the time in which the participants perform a short-term memory task (e.g. Jones and Macken, 1993). Already in the 1990's in a review about human performance during noise exposure, 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. He also claims 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.

Today many other studies share the same conclusion, that disruption depends largely on changes in pitch, timbre, or tempo as well as the finding that noise level does not seem to have much influence on performance (e.g. Banbury et al. 2001; Hughes and Jones, 2001). Moving the focus from the laboratory to the field shows that those studies with a more applied approach have come to the same conclusion. For example Hygge et al (2003) and Enmarker (2004) investigated the exposure of meaningful irrelevant speech and road traffic noise on different memory systems. The results showed that performance in a cued recall task measuring episodic memory was degraded when subjects were exposed to these noise sources. Even though the two auditory exposures are rather different in sound structure, no differences could be found on the impaired memory performance between the two noise sources. The authors from both studies concluded that the degraded 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.

Other common methods used to study the effects of noise exposure are subjective ratings. Often ratings of annoyance are used as a dependent variable in noise research and results shows that annoyance caused by noise exposure can be replaced interchangeably with feelings of being irritating or disturbing (Guski, 1997). Some of these studies give a quite varied picture. Key and Payne (1981) found higher annoyance ratings when people were working with mental tasks during exposure to a high frequency noise compared to when exposed to a low frequency noise. Other researchers found the opposite outcome when studying noise from ventilation systems (e.g. Persson Waye, Bengtsson, Kjellberg and Benton, 2001). Furthermore, Lundquist, Holmberg and Landstrom, (2000) established similar results when exploring the effects of classroom noise in schools but add that noise level is not important for the experience of rated annoyance.Studies using other outcome variables results shows that the presence of a recorded vehicle noise with a low frequency character make people subjectively experience feelings of stress (Ljungberg and Neely, 2007a). Thus, the reasons why people rate higher levels of negative feelings such as stress or annoyance during environmental noise exposures seem to be complex and the frequency and the character of the noise may be more important for the outcome than the noise level. Consequently, this is a conclusion that is shared with the results obtained from the studies of noise exposure and task performance (e.g. Banbury et al. 2001)

Not just the subjective ratings of noise exposure are important when measuring the experience of sound in the environment. 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. Some laboratory studies has shown that individuals who score high on noise sensitivity questionnaires have more degraded performance in a cognitive task than those who score low (e.g. Persson Waye, Bengtsson, Rylander, Hucklebridge, Evans and Clow, 2002; Belojevic, Öhrström and Rylander, 1992). While others could not find any stable performance effects related to noise sensitivity (Ljungberg and Neely, 2007a, 2007b). Some researchers believe that subjective noise sensitivity is more correlated to subjective judgments (Ellermeier, Eigenstetter, and Zimmer, 2001) and some claims that there is no clear relationship between noise exposure and subjectively rated noise sensitivity at all (Miederna and Vos, 2003).

Although many studies have examined the acute effects associated with noise and WBV, few studies have examined the after-effects associated with noise or other stressors such as 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). 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 airplane 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 Lindstrom and Mantysalo (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.

The general conclusion obtained from the findings in noise exposure and its effects on performance and subjective experiences both during and after exposure is summarized as follows. The variation in the sound structure is an important component when studying the effects on short-term memory performance (Banbury et al. 2001) and not only constructed sound sources, even road traffic noise with a changing structure may have the same, effect (Hygge et al. 2003). Furthermore, noise level seems to play a smaller role while frequency may be more important for the subjective experience when studying the effect of environmental noise exposure (e.g. Lundquist, Holmberg and Landstrom, 2000; Persson Waye et al. 2001). The after-effect caused by environmental noise sources might also have negative consequences for workers reaction time and experiences of fatigue (e.g. Kjellberg, Muhr, and Sköldström, 1998) causing a cumulative effect with long-term consequences. Considering that people have different personality traits may be of importance for the outcome when designing noise studies. People classified as "noise sensitive" might react different compared to people less sensitive to noise exposure (e.g. Weinstein, 1978).

3. PSYCHOLOGICAL EFFECTS OF WHOLE-BODY VIBRATION

The description of a whole-body vibration (WBV) is that it can be transmitted through a vibrating surface, and can affect all parts of the body when sitting, standing, or lying down. Most people are exposed to WBV in cars or trucks, where the vibration moves from the vehicle through the seat and footrest all the way to the head, even causing the head to move. WBV is known to have a negative effect on comfort, perception, and health (Mansfield, 2005).

Compared to noise exposure not many studies have examined the psychological effects of WBV on subjective judgments, cognitive performance, and the role of personality type. Kjellberg (1990) stated 17 years ago in his review article that visual perception and motor control tasks had already been well documented in WBV research. For example effects 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, while the knowledge of cognitive effects is rather small. A similar conclusion was drawn in a recent meta-analytic study (Conway, Szalma and Hancock, 2007).

Some of the more general conclusions from the available data on subjective judgements and WBV exposure are that doubling the vibration acceleration over a broad range of frequencies gives nearly a doubling in subjective intensity, an outcome also valid for subjective discomfort (Dempsey et al 1979). Kjellberg (1990) concludes that an individual's subjective sensitivity to vibration depends mostly on the frequency and is independent of acceleration level. This commonly agrees with the findings that ISO (1997a) relies on, showing that a person is most sensitive in the frequency range of 4-8 Hz in the vertical direction (Z) and in the fore-and-aft and lateral (X and Y) direction in the range 1-2 Hz. The author also found that researchers generally agree that subjective discomfort increases with exposure time. Similarly, in a case-control study by Abbate et al (2004) it was 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.

In addition to personality traits such as noise sensitivity, Webb, Bennett, Farmilo, Cole, Page and Withey (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, Lundstrom, and Björkvist, 2002).

As mentioned earlier, studies investigating cognitive effects of WBV are rather sparse. However, some studies have shown that a direct interference with reading speed and subjective ratings can be found when exposed to a fore-and-aft and a lateral WBV (Griffin and Hayward, 1994). 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 two studies by Sherwood and Griffin (1990, 1992) they used a 16 Hz sinusoidal vertical WBV. The latter study investigated the effects on learning in the magnitude 2.0 m/s^2. 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/s^2. They found an increase in response errors during only the 1.0 m/s^2, but no support was found for the hypothesis that a rising vibration magnitude generates greater 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.

WBV has also shown to have negative after-effects on performance in an attention task. Ljungberg K and Neely (2007b) found degraded performance in a search and memory task measuring selective attention after people had been exposed to a WBV. The noise and WBV used in the experiment were typical for those obtained in heavy vehicles and the participants were also conducting tasks that required high mental load during the exposures. Despite the degraded performance the participants experienced that they become more alert after the exposure to WBV compared to the exposure of a vehicle noise or to a control condition. The results indicate a complicated relationship between the measurements of subjective ratings versus performance, because people seem to be unaware of their mental degradation. This is a result that indicates how complex the relationship between task performance and subjective measurements are. People's experiences may not in all types of situations act as predictors of behaviour (Annett, 2002).

The general conclusion from the results obtained from WBV research and the effects on objective and subjective indices are that the frequency has a higher impact on rated annoyance than the acceleration level (Kjellberg, 1990; ISO, 1997a). Furthermore, personality traits measured with questionnaire techniques have showed that this might be of certain importance for the outcomes when studying exposure from WBV (Webb et al 1981; Abbate et al 2004) and people with high novelty seeking personalities tend to expose themselves longer than others (Neely, Lundstrom, and Björkvist, 2002).

Based on the research revealed when studying task performance, results also indicate that WBV seem to have an impact on certain cognitive functions measured by using short term memory tasks, and associative learning task (Sherwood and Griffin 1990, 1992) Furthermore, it is not only noise exposure that has been shown to cause after-effects. There are also results showing that an exposure from a single vibration may have negative consequences for people's attentional capacity after exposure is turned off (Ljungberg K and Neely, 2007b). On the other hand, still the body of data is rather small and more research is needed for higher criterion validity.

4. COMBINED EFFECTS OF NOISE AND WHOLE-BODY VIBRATION

The effects of combined noise and WBV on mental task performance were much more investigated 30 years ago and not many studies have been conducted more recently. However, the studies performed in the 70s showed that when combining noise and WBV in different frequencies and levels, the interaction effect may be complicated and hard to interpret. The results are mixed and seem to depend heavily on levels and frequencies and how they interact with the mental tasks. 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, Harris, Mohr, Nixon, Ohlbaum, Sommer, Thaler and Veghte, 1971; Grether, Harris, Ohlbaum, Sampson and

Guignard, 1972), a noise level that increases from 100 dB(A) to 110dB(A) combined with a 6 Hz (0.1_z m/s^2) vibration changed from a subtractive to an additive result (Sommer and Harris, 1973). Furthermore, Harris and Schoenberger (1980) established that a rise in noise level might not always increase the negative effects on performance. They found that 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/s^2) resulted in more adverse effects in a complex counting task than a 100 dB(A) noise stimulus combined with the same vibration. In addition, they found that a single 100 dB(A) noise and a single vibration stimulus negatively affected performance in a counting task. These results are in line with those found by Sandover and Champion (1984) when they studied the performance in an arithmetic task.

The general reflection of the mixed results from these studies is that the chosen stimuli in the studies are often very unnatural for the most common occupational environments (e.g. noise levels up to 110 dB(A) and WBV presented only in one direction) and results may not be representative for a vehicle environment. However, the mental tasks used in these studies (tracking tasks and arithmetic tasks) have demonstrated to be sensitive for the physical exposures used in research of combined effects and revealed that there can be a mechanical interference (tracking tasks) as well as an impairment on higher mental processes when using arithmetic tasks. Furthermore, a series of more recent studies with other cognitive tasks has been conducted where one of the aims was to investigate the combined effects of noise and WBV on performance and subjective experiences (Ljungberg, Neely, Lundstrom, 2004; Ljungberg K and Neely, 2007a, 2007b; Ljungberg K, 2007). In all the studies the general design was based on that the participants were exposed to a single noise or WBV exposure, both combined or a control condition with no environmental exposure. The cognitive tasks used were a short-term memory task developed by Sternberg (1966), a logical reasoning task developed by Baddely (1968) and a search and memory task measuring selective attention. The noise and WBV stimuli were all realistic exposures from vehicle environments (forwarders and helicopters). All of the tasks used have in other studies shown to be sensitive to WBV exposure (Sherwood and Griffin, 1990) or continuous free field noise (Smith and Miles, 1987) as well as realistic ventilation noise (Persson Waye et al 2002) and road traffic noise (Hygge et al 2003). Despite this, no combined effects generated by noise and WBV on performances were found in these studies. Interestingly, a combined effect was found in one of the studies on subjective ratings of annoyance and difficulty (Ljungberg, Neely, Lundstrom, 2004). This might be an interesting result because subjective judgments are sometimes seen as early indicators of other symptoms such as pain (Zhang, Helander, and Drury, 1996). Since the exposure time in most of the experiments are rather short (about 1-2 hours), longer exposures may show other results on performance.

Furthermore, a few more studies have been conducted on the combined effects of noise and WBV on subjective ratings. For example 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 (e.g. Howarth and Griffin, 1990a, 1990b; Nakamura et al 1990; Paulsen and Kastka, 1995; Ljungberg et al 2004). Although there might be an interaction, it may depend on the relative magnitude of the stimuli. 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 (Howarth and Griffin, 1990a, 1990b). For an overview of some of the studies that have been conducted in this topic, see Table 1

The complex environment may not only have negative effects for the mental processes and subjective experiences. There are also studies from other research areas that have shown that stressors such as noise and WBV may interact and that the results are not the same when studying one at a time as when combining both together. For example, several studies that have demonstrated combined effects of noise and WBV on physical parameters such as palm sweating (Sakakibara, Kondo, Koike, Miyao, Furuta, Yamada, Sakurai and Ono 1989), temporary threshold shifts (Seidel, Harazin, Pavlas, Sroka, Richter, Bluthner, Erdmann, Grzesik, Hinz and Rothne, 1988, Seidel, Erdmann, Bluthner, Hinz, Brauer, Arias and Rothe, 1990; Manninen, 1983; Manninen, 1984; Manninen, 1986), and genotoxicity (Silva, Carothers, Castelo Branco, Dias and Boavida, 1999a, 1999b).

Table 1 *Articles are presented within the fields of combined noise and whole-body vibration exposure. The table shows the environmental stimuli (noise and WBV exposure levels) type of cognitive task, subjective ratings and the results.*

Author	Environmental stimuli	Cognitive task	Subjective ratings	Results
Grether et al (1971)	Noise level 100- 105 dB(A) + 5 Hz WBV (0.30 peak g)	Tracking task	-	Fewer adverse effects on tracking by combined exposure, than by vibration alone
Grether el al (1972)	Noise level 100- 105 dB(A) + a 5 Hz WBV (0.30 peak g)	Tracking task	-	Fewer adverse effects on tracking by combined exposure, than by vibration alone
Sommer & Harris, (1973)	Noise level 100- 110 dB(A), + 6 Hz WBV (0.1_z m/S^2)	Tracking task	-	Combined effect changed from subtractive to additive effect when increasing noise level
Harris & Schoenberger, (l 980)	Noise level 65,100 dB(A), + complex WBV, 16 Hz, (0.36 m/s^2)	Complex counting task	-	Larger combined effects of noise and WBV when noise level was low.
Seidel et al (1988)	Noise level 92 dB(A) + 4 Hz (Z), l .0 m/s^2 WBV	-	Ratings of perceived strain and motivation	Motivation decreased during exposures independently of condition. Perceived strain was significantly higher in the vibration condition.
Howarth & Griffin. (1990a)	Noise level 59-84 dB(A) + 0.020 - 0.125 m/s^2 WBV	-	Ratings of preferences and annoyance	Higher ratings of annoyance when both noise and WBV were presented.
Ljungberg, Neely & Lundstrom, (2004)	Noise level 77- 86 dB(A) + 16 Hz (Z) 1.0-2.5 m/s^2 WBV	Short-term memory task	Ratings of intensity, difficulty and annoyance	Higher ratings of difficulty and annoyance when noise and WBV were combined. No effect on performance.
Ljungberg K & Neely. (2007a)	Noise level 78 dB(A) + 2-4 Hz, 1 . 1 m/s^2 WBV	Logical reasoning task and a Short -term memory task	Ratings of stress and difficulty.	Higher ratings of stress were found when noise and WBV were combined. No effect on performance.

DISCUSSION

The main purpose with this review was to shed some light over a rather unknown research area, the one that concerns the combined effects of noise and WBV. Since many workers such as the tree harvester described at the beginning of the paper, are exposed everyday to noise and WBV and at the same time are under high mental load, it is important to gain more knowledge about this topic. Degraded cognitive performance during maneuvering for example a heavy vehicle, may lead to injury or accidents. Furthermore, it is important to broaden the knowledge in this area since the international standards and regulations that govern acceptable occupational exposure levels for noise and WBV do not take into consideration possible interactions between these two stressors (ISO 1997a; ISO 1999), and neither do they provide guidelines that address the effects of noise or WBV exposure on mental tasks (ISO 1997a, 1997b; ISO 1999).

With regard to working environments, the general conclusion drawn from the number of studies conducted so far in this research area is that most of the environmental stimuli used in the studies not been realistic. Focus has been on noise exposures with high levels and the WBV stimulus has been presented most commonly in only one direction (e.g. Grether et al.1971; Grether, 1972). Furthermore, motion presented in only one direction is not similar to naturalistic WBV obtained in vehicle environments which are measured in three directions and rotated (ISO 1997a). Only a few more recent studies has used more realistic environmental stimuli, similar to vehicle environments, but no combined effects was obtained on performance in those studies (e.g. Ljungberg, Neely, Lundstrom, 2004). The performance tasks that have been used and proved to be sensitive are the motor control tasks (e.g. Grether et al 1971; Grether et al 1972) which indicate a more physical interference while the arithmetic tasks used shows that even higher mental processes may be effected (e.g. Sandover and Champion, 1984; Sommer and Harris, 1973).

Studies that have used subjective ratings as a method have been more unanimous, showing that when combining noise and WBV the experience is more commonly negative (e.g. Manninen, 1990, Howarth and Griffin, 1990a; Ljungberg et al 2004). It seems that the combined effects of noise and WBV are more easily revealed when using subjective measurements and the relationships between the combined effects and mental performance are more complex. However, subjective ratings have shown to be good predictors and act as early indicators of symptoms such as pain (Zhang, Helander and Drury, 1996), and exposure time may therefore play an important role in the experiments. Most of the studies conducted have been controlled laboratory studies with rather short exposure times. Other measurable outcomes could appear if the exposure times were increased and were more similar to real working conditions.

For further research of combined effects on psychological responses, learning from the findings obtained in single noise/sound or WBV studies might raise a number of new ideas. Several results obtained from theoretically based studies of the irrelevant sound and the effect on short-term memory and attention has shown that certain mental processes such as for example serial memory is particularly prone to sounds with a changing character, particularly sounds that vary in pitch, timbre or tempo (Jones et al 1992). Serial recall is a short-term memory task where participants are exposed to for example a set of digits (1-9) and after the presentation are asked to recall the items in the exact order as they earlier saw them. This is an issue that may be worth investigating in more applied domains, since holding things in memory in a specific order is a skill used in many working situations. For a comprehensive review of existing knowledge about the effects of irrelevant sounds and short-term memory, see Banbury et al. (2001).

Not only studies of irrelevant sound from theory based research have concluded that it is the changing character of the noise that affects memory. For example, a cued recall task measuring episodic memory has been shown to be sensitive to road traffic noise and meaningful irrelevant speech (Hygge et al 2003; Enmarker, 2004). Both of these two sound sources are not unlike the noise exposures that can be found in for example vehicle drivers' environments.

Considering the findings from single noise and WBV studies, the knowledge of aftereffects caused by environmental noise or WBV exposure on performance and subjective ratings (e.g. Kjellberg, Muhr, and Skoldstrom, 1998; Ljungberg K and Neely, 2007b) is most valuable from 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 might influence task performance negatively depending on the types of activities that the workers participate in between or after a workshift. Moreover, there are also other reasons as to why after-effects should be of interest for the studies of combined effects of noise and WBV. Cohen (1980) found that it is not likely that only one isolated stressor (such as noise or vibration) can cause behavioral after-effects alone. He assumes that after-effects are caused by multiple stressors.

Do you remember the tree-harvester described from the beginning of the introduction? How do we apply what we know so far about the combined effects of noise and WBV on mental load and subjective experience on his working situation? First, if the results generated so far can be generalised to real life situations, combined exposure to noise and WBV may lower his mental capacity if he would have to do counting. The exposures from the vehicle may also result in degraded ability for tracking. If he starts to experience his working situation as annoying, stressful, and difficult, the outcome after long-term exposure is hard to predict based on the result from the studies conducted so far. Still, research from WBV indicates that long-term exposure may affect him negatively and increase the risk for emotions such as fatigue, depression, and tension. 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. Some results indicate also that short exposures to WBV can have negative effects on attention performance and this may have implications for our tree-harvester. For example, it may be important that after a 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.

REFERENCES

Abbate, C., Micali, E., Giorgianni, C., Munao, F., Brecciaroli, R., Salmaso, L., & Germano, D. Affective correlates of occupational exposure to whole-body vibration. A case-control study. Psychoth Psychosom. 2004, 73, (6), 375-379.

Annett, J. Subjective rating scales: science or art? Ergonom. 2002, 45, (14), 966-987.

Baddeley, A. D. A 3-min reasoning test based on grammatical transformation. Psychonom Sci. 1968, 10, (10), 341-342.

Banbury, S. P., Macken, W. J., Tremblay, S., & Jones, D. M. Auditory distraction and Short-term memory: Phenomena and practical implications. *Hum Fact*. 2001, 43, (1), 12-29.

Belojevic, G., Ohrstrom, E., & Rylander, R. Effects of noise on mental performance with regard to subjective noise sensitivity. *Int Arch Occup Environ Health*. 1992, 64, 293-301.

Cohen, S. After-effects of stress on human performance and social behaviour: A review of research and theory. Psychol Bul. 1980, 88, (1), 82-108.

Conway, G. E., Szalma, J. L., and Hancock, P. A. A quantitative meta-analytic examination of whole-body vibration effects on human performance. Ergonom. 2007, 50, (2), 228-245.

Dempsey, T. K., Leatherwood, J. D. Clevenson, S. A. Development of noise and vibration ride comfort criteria. J Acoust Soc Am. 1979, 65, (1), 124-132.

Ellermeier, W., Eigenstetter, M., & Zimmer, K.. Psychoacoustic correlates of individual noise sensitivity. J Acoust Soc Am. 2001, 109, (4), 1464-1473.

Enmarker, I. The effects of meaningful irrelevant speech and road traffic noise on teachers attention, episodic and semantic memory. *Scand J Psychol*. 2004, 45, 393-405.

Grether, W. F., .Harris, C. S., Mohr, G. C., Nixon, C. W., Ohlbaum, M., Sommer, H. C., Thaler, V. H., & Veghte, J. H. Effects of combined heat, noise and vibration stress on human performance and physiological functions. Aerospace Med. 1971. 42 (10), 1092-1097.

Grether, W. F., Harris, C. S., Ohlbaum, M., Sampson, P. A. Guignard, J. C. Further study of combined heat, noise and vibration stress. Aerospace Med. 1972, 43, (6), 641 -645.

Griffin, M. J., & Hayward, R. A. Effects of horizontal whole-body vibration on reading. Appl Ergonom. 1994, 25, (3), 165-169.

Guski, R. Psychological methods for evaluating sound quality and assessing acoustic information. Acta Acoust. 1997, 83, 765-774.

Harris, S. C., & Shoenberger, R. W. Combined effects of broadband noise and complex waveform vibration on cognitive performance. Aviat Space Environ Med. 1980, 51, (1), 1-5.

Howarth, H. V. C., & Griffin, M. J. Subjective response to combined noise and vibration: Summation and interaction effects. *J Sound Vib*. l990a, 143, (3), 443-454.

Howarth, H. V. C., & Griffin, M. J. The relative importance of noise and vibration from railways. *Appl Ergonom*. l 990b, 21, (2), 129-134.

Hughes, R., & Jones, D. M. The intrusiveness of sound laboratory findings and their *implications for noise abatement. Noise & Health*. 2001, 4, (13), 51-70.

Hygge, S., Boman, E., & Enmarker, I. The effects of road traffic noise and meaningful irrelevant speech on different memory systems. *Scand J Psychol.* 2003, 44, (1): 13-21.

ISO (1997a). “Mechanical vibration and shock - Evaluation of human exposure to whole body vibration - Part 1: General requirements”, ISO 2631 - 1:1997 (E), ISO. Geneva. Switzerland

ISO (1997b). Acoustics-Guidelines for the measurement and assessment of exposure to noise in a working environment. ISO 9612. Geneva. Switzerland.

ISO (1999). Acoustics Determination of occupational noise exposure and estimation of noise-induced hearing impairment. ISO 1999. Geneva. Switzerland

Jones, D. *M. Recent advances in the study of human performance in noise. Environ Int*. 1990, 16, 447-458.

Jones, D. M., Madden, C. & Miles, C. Privileged access by irrelevant speech: The role of changing state. Quart J Exp Psychol. 1992, 44A, 645-669.

Jones, D. M., & Macken, W. Irrelevant tones produce an irrelevant speech effect: Implications for phonological coding in working memory. *J Exp Psychol: Learn, Mem Cogn*. 1993, 19, 369-381.

Key, K. F., & Payne, M. C. Jr. Effects of noise frequency on performance and annoyance for women and men. Percept Mot Skills. 1981, 52, (2), 435-41.

Kjellberg, A. Psychological aspects of occupational vibration. Scand J Work, Environ Health. 1990, 16, 1, 39-43.

Kjellberg, A., Muhr, P. and Skoldstrom, B. Fatigue after work in noise - an *epidemiological survey study and three quasi-experimental field studies. Noise & Health*. 1998, 1, 47-55.

Lindström K & Mantysalo (1981) Attentive behaviour after exposure to continuous industrial noise. I. G. Salvendy & M. J. Smith (Ed.) Machine Pace and Occupational Stress (pr 91-96) Taylor & Francis. London

Ljungberg, J., Neely, G., & Lundstrom, R. Cognitive performance and subjective experience during combined exposure of whole-body vibration and noise. *Int Arch Occup Environ Health*. 2004, 77, 217-221.

Ljungberg K, J., & Neely, G. Stress, subjective experience and cognitive performance during exposure to noise and vibration. *J Environ Psychol*. 2007a, 27, 44-54. (A)

Ljungberg K, J., & Neely, G. Cognitive after-effects of vibration and noise exposure and the role of noise sensitivity. *J Occup Health*. 2007b, 49, 111-116. (B)

Ljungberg K, J. Cognitive degradation after exposure to combined noise and wholebody vibration in a simulated vehicle ride. Int J Vehicle Noise Vib. 2007, 3, (2), 130-142.

Lundqvist, P., Holmberg, K., & Landstrom, U. Low frequency noise and annoyance in classroom. J Low Freq. Noise Vib Act Cont. 2000, 19, 4, 175-182.

Manninen, O. Further studies on changes in subjective stressfulness under various combinations of noise, vibration, temperature and work tasks. Arch Compl Environ Stud. 1990, 2, (2), 31-39.

Manninen, O. Bioresponses in men after repeated exposures to single and simultaneous sinusoidal or stochastic whole body vibrations of varying bandwidths and noise. *Int Arch Occup Environ Health*. 1986, 57, 267-295.

Manninen, O. Hearing threshold and heart rate in men after repeated exposure to dynamic muscle work, sinusoidal vs. stochastic whole body vibration and stable broadband noise. *Int Arch Occup Environ Health*. 1984, 54, 19-32.

Manninen, O. Studies of combined effects of sinusoidal whole body vibrations and noise of varying bandwidths and intensities on TTS2 in men. *Int Arch Occup Environ Health*. 1983, 51, 273-288.

Mansfield, N. J. Human response to vibration. CRC Press LLC. 2005, Boca Raton.

Miedema, H. M., & Vos, H. Noise sensitivity and reactions to noise and other environmental conditions. J Acoustic Soc Am. 2003, 113, (3), 1492- 1504.

Nakamura, H., Nohara, S., Nakamura, H., Kajikawa, Y., & Okada, A. Field study on subjective responses to noise and vibration. Arch Compl Environ Stud. 1990, 2, (3), 25-32.

Neely, G., Lundstrom, R., & Bjorkvist, B. Sensation seeking and subjective unpleasantness ratings of stimulus intensity. *Percept Mot Skills*. 2002, 95, 706-712.

Paulsen, P. & Kastka, J. Effects of combined noise and vibration on annoyance. *J Sound Vib*. 1995, 181, (2), 295-314.

Persson Waye, K., Bengtsson, J., Kjellberg, A., & Benton, S. Low frequency noise *"pollution" interferes with performance. Noise & Health*. 2001, 4, (13), 33-49.

Persson Waye, K., Bengtsson, J., Rylander, R., Hucklebridge, F., Evans, P., & Clow, A. Low frequency noise enhances cortisol among noise sensitive subjects during work performance. *Life Sci.* 2002, 70, 745-758.

Sakakibara, H., Kondo, T., Koike, Y., Miyao, M., Furuta, M., Yamada, S., Sakurai, N., & Ono, Y. Combined effects of vibration and noise on palmar sweating in healthy subjects. Europ J Appl Physiol Occup Physiol. 1989, 59, (3), 195-198.

Sandover, J., & Champion, D. F. Some effects of a combined noise and vibration environment on a mental arithmetic task. J Sound Vib 1984, 95, (2), 203-212.

Seidel, H., Erdmann, U., Bluthner, R., Hinz, B., Brauer, D.,Arias, J. F., Rothe, H. J. Evaluation of simultaneous exposures to noise and whole-body vibration by magnitude estimation and cross-modality matching- an experimental study with professional drivers. Arch Compl Environ Stud. 1990, 2, (3), 17-24.

Seidel, H., Harazin, B., Pavlas, K., Sroka, C., Richter, J., Bluthner, R., Erdmann, U., Grzesik, J., Hinz, B., Rothne, R. Isolated and combined effects of prolonged exposures to noise and whole-body vibration on hearing, vision and strain. *Int Arch Occup Environ Health*. 1988, 61, 95- 106.

Sherwood, N., & Griffin, M. J. Effects of whole-body vibration on short-term memory. *Aviat Space Environ Med*. 1990, 61, 1092-1097.

Sherwood, N., & Griffin, M. J. Evidence of impaired learning during whole-body vibration. J Sound Vib. 1992, 152, (2): 219-225.

Silva, M. J., Carothers, A., Castelo Branco, N., Dias, A., & Boavida, M. G. Sister chromatid exchange analysis in workers exposed to noise and vibration. Aviat Space Environ Med. l999a, 70, (3 pt 2), A40-45.

Silva, M. J., Carothers, A., Castelo Branco, N., Dias, A., & Boavida, M. G. Increased levels of sister chromatid exchanges in military aircraft pilots. Mutat research. 1999b, 441, (1): 129-134.

Smith, A. *P. Noise and aspects of attention. Brit J Psychol*. 1991, 82, 313-324.

Smith, A. P. Acute effects of noise exposure: an experimental investigation of the effects of noise and task parameters on cognitive vigilance tasks. Int Arch Occup EnvironHealth. 1988, 60, 307-310.

Smith, A. P., & Miles, C. The combined effects of occupational health hazards: an experimental investigation of the effects of noise, night-work and meals. *Int Arch Occup Environ Health.* 1987, 59, 83-89.

Sommer, H. C., & Harris, C. S. Combined effects of noise and vibration on human tracking performance and response time. Aerospace Med. 1973, 44, 276-281.

Sternberg, S. High speed scanning in human memory. Sci. 1966, 53, 652-654.

Webb, R. D. G., Bennett, M. D., Farmilo, B., Cole, S. H., Page, S. J., & Withey, W. R. Personality and inter-subject differences in performance and physiological cost during whole-body vibration. Ergonom. 1981, 24, (4), 245-255.

Weinstein, N. D. (1978). Individual differences in reactions to noise: A longitudinal study in a college dormitory. J Appl Psychol. 1978, 63, (4), 458-466.

Zhang, L., Helander, M. G., & Drury, C. G. Identifying factors of comfort and discomfort in sitting. Hum Fact. 1996, 38, (3), 377-389.

QATAR'S NOISE REGS

Qatar does have rules on the maximum limits of noise levels, divided separately as residential, commercial and industrial areas. The day time maximum noise allowed at residential areas and public corporations is 55dB (A) and 45 for nights. For commercial areas, it is 65 and 55dB (A) and for industrial facilities it is 75 and 75dB (A) for day and night respectively. These may be implemented at major industrial establishments but it is not clear who should enforce the rule around roadways; this was a grey area between the Environment Ministry and the Traffic Department.

LONG-LASTING BATTERIES CAUSING LONG-TERM HEARING DAMAGE

As more and more teenagers plug into MP3 players like the iPod, doctors in the US and Hong Kong are reporting more young patients with hearing loss problems. The same fears were raised when Walkmans were introduced in the '80s. But now, doctors say the problem will only get worse, because the latest music devices have longer-lasting batteries. This is because hearing damage is directly related to the duration of exposure. So one fear is that steady, long-term exposure to even moderately loud music could result in premature hearing loss. Said Dr Robert Fifer, director of audiology and speech pathology at the University of Miami's Mailman Centre for Child Development: 'Once these things became portable and full-time usable, we really started noticing more noise-induced hearing-loss problems in younger children.' The same thing is being reported by doctors in Hong Kong. Said Dr Michael Tong Chi-fai, chief of otorhinolaryngology at Chinese University: 'It used to be rare for people in their 20s or 30s to show noise-induced hearing loss, but these cases are quite common now.' Hearing specialists expect the situation to get worse because accumulated noise damage can take years before it causes noticeable problems. More than half of American high school students have at least one symptom of hearing loss, says another study by the American Speech-Language-Hearing Association. Across the Pacific, between 5 per cent and 7 per cent of secondary school students in Hong Kong suffer from mild hearing problems, says a 2007 survey.

CLASSROOM NOISE CONCERN

Noisy classrooms are preventing children from learning and taking a health toll on teachers, according to Canadian experts who want the federal government to adopt national sound standards for new schools and improvements made to existing ones. "Excessive background noise and poor acoustics can lead to poor understanding of the speech signal, decreased performance by students, reading deficiencies, delayed language acquisition and many other negative consequences," Linda Walsh, president of the Canadian Association of Speech Language Pathologists and Audiologists, said at a press conference in mid January. Walsh's association is one of 18 that make up the Concerned About Classrooms Coalition, and it says the absence of standardized classroom acoustics is a gap that must be filled. The coalition is recommending Canada follow a model already developed in the United States by the Acoustical Society of America that established specific criteria for maximum background noise and reverberation times for classrooms depending on their size. Lighting fixtures, computers, heating and air conditioning units, outdoor noise from traffic or the schoolyard, and normal classroom sounds like chairs scraping on the floor can all make it difficult for students to hear their teachers and it's even more of a challenge for children with learning disabilities or hearing loss or students who are learning in a second language, the experts said. One in six words is not understood by the average Grade 1 student because of the excessive noise and poor acoustics in classrooms, according to the group.