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Cognitive After-effects of Vibration and Noise Exposure and the Role of Subjective Noise Sensitivity

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Abstract: Cognitive After-effects of Vibration and Noise Exposure and the Role of Subjective Noise Sensitivity: Jessica K. LJUNGBERG, *et al.* National Institute for Working Life, Sweden—This study investigated the effects on attention performance after exposure to noise and whole-body vibration in relation to subjective noise sensitivity. Sixteen high and 16 low sensitivity male students, as determined by the Weinstein Noise Sensitivity Questionnaire, participated in a within-subjects experiment. Noise and vibration stimuli similar to those usually occurring in forestry vehicles were presented either individually, combined or not at all in four separate sessions lasting approximately 44 min. After exposure, participants completed an attention task and made subjective ratings of alertness. No main effect of noise sensitivity was observed in MANOVA, thus the data was pooled with the data from a pilot study using the exact same procedure without using a noise sensitivity inclusion criterion. The combined data revealed performance degradation in the attention task after exposure to vibration, regardless as to whether it was presented alone or in combination with noise. Increased ratings of alertness after vibration exposure and decreased ratings of alertness after noise exposure were also found. Neither synergistic nor antagonistic effects were observed from the combined noise and vibration exposure.
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Key words: Noise sensitivity, Attention, Alertness

Professional drivers are exposed to many types of stress. Some stressors, such as a bus driver's responsibility to keep to a schedule, are well known. Other stressors, such as exposure to noise or vibration, are less obvious. The physical effects generated by exposure to noise and vibrations have been extensively studied and are the bases of the international standards that govern acceptable occupational exposure levels. Less studied and understood, however, is the effect such exposures have on mental performance. Studies indicate that exposure to either of these stimuli can produce negative effects on cognitive performance[1–7], even the combination of the two also produces negative effects[3, 6, 7].

From studies of the physical effects of exposure to noise and vibration, it is known that there are after-effects related to prolonged or intensive exposure. Temporary shifts in hearing and touch thresholds are examples of such effects. Some after-effects are clearly evident after the exposure has ceased, such as a ringing in the ears or muscle fatigue. Few studies have examined the post-exposure effects of noise or vibration on cognitive performance. In a review of the psychological effects of occupational vibration, Kjellberg[8] noted that the knowledge about vibration after-effects is rather meagre and that more studies would be useful in this area.

Studies that have investigated the cognitive after-effects from noise exposure are more abundant. Glass and Singer[9] were among the first to demonstrate after-effects on mental performance. An unsolvable puzzle was used to measure task motivation after exposure to an uncontrollable noise. They found that predictability and the possibility of controlling the noise reduced the cognitive after-effects. Similarly, Evans and Johnson[10] found that participants who had been exposed to 3 h of simulated office noise made fewer attempts at unsolvable problems compared to a control group.

After-effects are particularly interesting from a workplace perspective. In many situations, workers are exposed to noise and vibration for relatively short periods several times during a work shift. The degree and length of any decrease in cognitive performance after exposure to noise and vibration would have direct implications on

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the types of activities that it would be appropriate for workers to participate in between such exposures or after a work-shift. Lindström and Mäntysalo[11] measured effects before, in the middle, and after a work-shift on a reaction time task after exposure to industrial noise. While not significant, the results indicated a trend towards a decrease in reaction time after being exposed to noise during the work-shift. Ljungberg, Neely, and Lundström[12] reported significantly longer reaction times in a spatial ability test in individuals who had been exposed to 20 min of a low frequency noise at 81 dB, compared to those individuals who were exposed to the same frequency noise at 77 or 86 dB.

One of the more salient examples of combined whole body vibration and noise exposure in the field is the operation of large vehicles or machinery such as those found in agriculture, forestry and construction work. A common characteristic of these types of vehicle is that they generate a relatively low frequency noise. Persson Waye *et al.*[2] found that subjects who were classified through a noise sensitivity inventory as highly sensitive to low frequency noise performed worse on cognitive tasks when exposed to a low frequency noise than subjects who where classified as lowly sensitive. Belojevic, Öhrström, and Rylander[14] concluded that subjects without noise sensitivity performed better than noise sensitive subjects on cognitive tasks. Additionally, this research noted that subjects without noise sensitivity found noise exposure less annoying than sensitive subjects found.

Investigating noise annoyance and noise sensitivity is not a new research topic. In recent years, many studies have focused on the relationship between noise exposure, subjectively rated noise sensitivity, and cognitive performances. The results from these studies, however, have been inconsistent.

Weinstein[15] developed the noise sensitivity scale, a tool to measure attitudes and reactions to daily noise exposure. Weinstien's results with a student population indicate that noise sensitive students are lower in scholastic ability and have a greater desire for privacy than noise insensitive students. The noise sensitivity parameter predicted individual reactions to environments encountered for the first time or encountered on repeated occasions. While some researchers have had difficulties in finding a clear relationship between noise sensitivity and performance measures[19–21], others have indeed found both cognitive and biological effects[2, 14].

These previous studies on noise sensitivity focused largely on classroom and office environments which qualitatively are quite different from the environments experienced by those who are exposed to whole-body vibration and noise. Further, they have generally focused either on effects during exposure or on chronic effects. However, in a pilot study we conducted with 24 male participants who performed a cognitive task immediately after exposure to noise and vibration (either alone or combined) we found that noise sensitivity may even influence after-effects. Noise sensitivity status was determined post hoc by scores from the Weinstein Noise Sensitivity Questionnaire[15]. We found that noise sensitivity scores were heavily skewed towards low sensitivity, thus an analysis was conducted focusing only on the participants scoring in the upper and lower quartiles. This analysis showed that there was a difference in attention performances between these two groups; the upper quartile group made more errors than the lower quartile group. This result was supported by the results generated from a correlation analysis. It is difficult to draw any conclusion on such a small sample because of its low power, but studies have found that noise sensitivity may have a moderating role in cognitive performance during noise exposure[2, 14] and the results seen in the pilot study indicate that it may even have a role in performance after exposure.

Against this background, we conducted an experiment to explore if there are post-exposure effects on performance of a search and memory task and to see if such effects are moderated by subjective noise sensitivity. The exposures and procedure were identical to the pilot study with the exception that participants were screened beforehand for noise sensitivity and included in the study only when scoring below or above specific criteria values on the Weinstein Noise Sensitivity Questionnaire. The noise and vibration stimuli used were designed to replicate the sensory experience of riding in a forwarder, a vehicle used in forestry work to collect and transport logs to a central pick-up point. This vehicle type was chosen in part because it produces low frequency vibrations which are known to have physically negative effects and in part because it is subjectively experienced as uncomfortable[13]. Further, similar vehicles are found in a number of different industrial settings, such as construction work, inventory management and transportation. We hypothesized that the results from the pilot study would be confirmed and that differences in performance would be moderated by subjective noise sensitivity.

Methods

Participants

Two groups were selected using a self-reported high or low sensitivity to noise exposure. A total of 201 Noise Sensitivity Questionnaires were distributed to men attending courses at Umeå University. Questionnaires were returned by 134 (mean score 68 points, SD=13.4, range 36 to 98). A Low Sensitivity group (n=16, mean age of 24, SD 2.94) and a High Sensitivity group (n=16, mean age 23, SD 2.46) were formed by first selecting the lower and upper 25 percentiles (n=67). Then, by including only those who had indicated on their questionnaire that they would be interested in participating in a study (n=54), the 30% highest and lowest scores were used to form the groups. All of the participants reported being in good physical health. They were naive about the aim of the experiment and none of them had been included in the pilot study. The participants were included in a larger data collection (see procedures section) where measurements of cortisol levels were taken. Only males were used because there can be gender differences in saliva cortisol measures[16].

Materials

Sinusoidal whole-body vibration was generated in three directions (in accordance with ISO 2631)[13]. The vibrations were presented and rotated at an acceleration of 1.1 m/s^2 r.m.s. at three frequencies: 2 Hz in the X direction, 3.15 Hz in Y direction, and 4 Hz in Z direction. The vibrations were generated using a hydraulic vibrator with 6-degrees of freedom attached to a motion platform (Rexroth, HSE-6-MS-8-L-3D). A seat from a typical forwarder was mounted onto the platform (KAB 554 THOR AIR). Frequency levels and proportions between the three directions were chosen to mimic the vibrations typically produced by a forwarder moving on a non-paved surface. The acceleration level was selected by consulting the recommendations from European Union Directive 2002/44/ec, a directive that regulates vibration exposure for an eight-hour working day.

The noise stimulus was an authentic low frequency noise from a forwarder. The noise was recorded in the cabin as it moved without a load. In the laboratory, participants were exposed to the noise at 78 dB(A) through two loudspeakers that were positioned in front of them . The noise level was continuously monitored with a sound level meter (Brüel & Kjær 2237) measured close to the participants ears, and the background noise remained steady at 45 dB(A). The sound levels were based on the results from a pilot study in which cross-modality matching was used to find a level of the noise stimulus that matched the chosen vibration magnitude to subjective annoyance.

Cognitive task

A search and memory task (SAM) was used to measure attention performance and it was selected because of its high memory load character and the small learning effects[17]. The task was conducted with a paper and pen. A random order of letters written on a piece of paper was presented to the participants. At the beginning of each row, there were five target letters. The participants were asked to memorize the letters and then search for them among the following line of 59 letters. The participants were told 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. Each line contained 0–4 target letters. Number of errors, speed (number of letters completed) and accuracy (percentage of errors) were measured as dependent variables. Different versions of target and search sets were used for each condition to avoid learning effects.

Rating scales and the noise sensitive questionnaire

The participants rated alertness using a Borg CR-10 rating scale[18], which includes verbal anchors combined with a roughly logarithmic numerical scale, ranging from 0 (nothing at all) to 10 (extremely strong). To avoid ceiling effects, an absolute maximum is located outside the number scale. Participants were instructed to first chose the verbal expression that best described their experience and then to adjust their response using the numerical scale.

A Swedish version of the Noise Sensitivity Questionnaire developed by Weinstein[15] was used in the current study. The translated version has also been used in other studies[2, 14].

Experimental design

Participants were exposed, individually, on separate occasions to four different environmental conditions: vibration, noise, vibration and noise combined and a control condition without either stimulus. Condition order was randomised among the participants.

Procedure

This study is part of a larger data collection where other parameters were measured. The following description includes even the parts of the procedure that weren't used in the present study.

Each participant came to the laboratory at the same time of the day for all four test conditions, and all tests were conducted during the daytime, in order to control for circadian rhythms and natural variations in cortisol.

The first experimental session started with a familiarisation phase where the participants were given both written and verbal instructions concerning the test and procedure. A consent form was signed and a hearing test was conducted to ensure that all participants had normal hearing. The participants were instructed on how to sit in an upright position on the motion platform during the exposure and how to fill in the rating scale. A brief presentation of the noise and vibration stimuli was given, and the participants were allowed to practice two cognitive tasks that they were going to perform during the test session.

During the exposures and in the control condition, the participants conducted a short-term memory task and a logical reasoning task. Total exposure time was approximately 44 min (SD=4.3). Before exposure started and after the logical reasoning task was completed, saliva cortisol was collected. After the exposure, participants were taken to another room (the transfer time took

Table 1. Mean values (and standard deviations) of the outcome variables, accuracy (% of errors), speed (number of letters scanned) and rated alertness for the Low and High Noise Sensitivity groups

	Search and memory task		
	Accuracy	Speed	Rated Alertness
Low sensitivity group (n=16)			
Noise only	1.6 (0.4)	924 (247)	3.4 (1.4)
Vibration only	1.7 (0.5)	931 (360)	3.5 (1.8)
Combined	1.7 (0.3)	951 (373)	3.5 (1.2)
Control	1.7 (0.5)	888 (359)	3.4 (1.7)
High sensitivity group (n=16)			
Noise only	1.5 (0.4)	993 (326)	2.4 (1.1)
Vibration only	1.6 (0.4)	1,029 (359)	3.2 (1.5)
Combined	1.8 (0.6)	1,030 (349)	3.1 (1.3)
Control	1.4 (0.6)	1,012 (383)	3.1 (1.4)

Table 2. Means and standard deviations of the pooled data from both the experiment and the pilot study (n=56), showing rated alertness and accuracy (% of errors), speed (number of letters scanned) and number of errors in the search and memory task

	Search and memory task			
	Accuracy	Speed	Errors	Rated Alertness
Noise only	1.5 (0.5)	926 (298)	14.8 (7.8)	3.1 (1.5)
Vibration only	1.7 (0.5)	948 (350)	16.6 (9.4)	4.0 (1.7)
Combined	1.6 (0.5)	943 (335)	15.8 (9.7)	3.5 (1.6)
Control	1.5 (0.5)	891 (325)	14.0 (8.5)	3.5 (1.8)

approximately 30 s) and completed the attention task (SAM) for five minutes. As soon as they had finished the task, they rated how alert they felt.

Statistical methods

All statistical analyses were initially analysed using a three way repeated measures MANOVA, with dependent variables of performance (accuracy and speed) and rated alertness. The independent variables were vibration (not present, present) and noise (not present, present). Noise sensitivity was used as a between-subject factor.

Number of errors and speed were analyzed only as a complement to accuracy when the results needed to be further explored. Two-tailed correlation analyses were also made for all data using Pearson's correlation coefficient. For all the analyses, an alpha level of .05 was interpreted as a significant effect.

Results

Means and standard deviations for all variables are presented in Table 1. The two way repeated measures MANOVA revealed no between group effects of noise sensitivity ($F(1,30)=0.325$, $p=.573$). Given that the noise sensitivity status of the participant was the only procedural difference between the data from the pilot study (n=24) and the present experiment (n=32), the MANOVA was recalculated using the pooled data (n=56) from both experiments and without using the between groups variable noise sensitivity in order to increase the power in examining for after-effects. The pooled data is presented in Table 2.

A significant main effect of vibration exposure was found for accuracy ($F(1,55)=4.435$, $p=.040$). Participants had lower performance in SAM in the conditions where vibration was present compared to those conditions where it was not present (see Fig. 1). Further, it was seen that participants performed the task significantly faster ($F(1,55)=4.669$, $p=.035$) and committed more errors ($F(1,55)=8.889$, $p=.004$) after the vibration conditions.

Significant main effects were found on perceived alertness in both the noise exposure conditions ($F(1,55)=6.958$, $p=.011$) and in the vibration exposure conditions ($F(1,55)=5.016$, $p=.029$). Participants' ratings of alertness were lower when noise was present compared to when it was not present and ratings of alertness where higher when vibration was present compared to when it was not present.

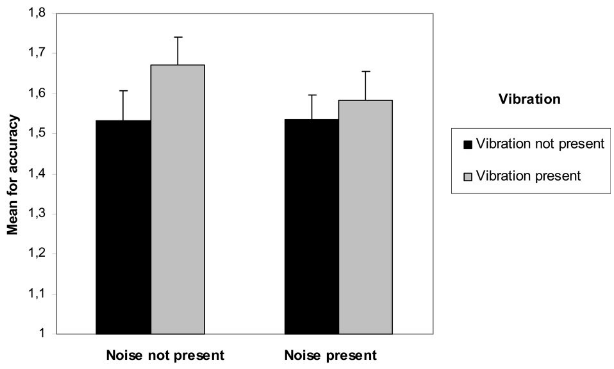

Fig. 1. Average (error bars represent standard error) percentage of errors in the four conditions for the pooled data from the experiment and the pilot study (n=56).

Correlation analysis

The correlation analysis was conducted only on the data from the present experiment.

Low sensitivity group: A positive relationship was found between speed and rated alertness in the noise condition (r_{xy}=.499, n=16, *p*=.049), indicating that in the higher ratings of alertness, more letters were scanned.

Positive relationships were also noted between accuracy and speed after noise exposure (r_{xy}=.673, n=16, *p*=.004), vibration (r_{xy}=.790, n=16, *p*<.001), combined condition (r_{xy}=.968, n=16, *p*<.001) and control condition (r_{xy}=.753, n=16, *p*=.001). The higher the speed was in scanning the letters, the more errors were made.

High sensitivity group: As was seen with the Low Sensitivity group, a positive relationship between accuracy and speed was also found in the noise condition (r_{xy}=.920, n=16, *p*<.001), vibration (r_{xy}=.918, n=16, *p*<.001), combined condition (r_{xy}=.854, n=16, *p*<.001) and in the control condition (r_{xy}=.896, n=16, *p*<.001).

Discussion

The objective of this study was to test the hypothesis that noise sensitivity would play a moderating role in subjective ratings and performance in a search and memory task after exposure to different environmental stimuli. Other than the fact that subjective alertness was positively related to speed in the low noise sensitivity group and not in the high noise sensitivity group, no significant differences between the two groups were found. Studies that have found evidence of noise sensitivity on performance have measured cognitive ability during exposure and not after exposure and found moderate[2, 14], weak or no effects[19–20]. The results seen here indicate that noise sensitivity does not seem to be a factor in post-exposure performance. It should be noted that the other studies have used both male and female subjects while in the present work only males were tested. Gender has not previously been found to be a significant factor affecting noise sensitivity scores[15, 23]. However, gender has been found to affect cognitive performance in different types of tasks[24, 25], and thus the role of gender in the present paradigm could be further explored.

We increased the power in the study by combining the data with the results from a pilot study and it was seen that performance was significantly poorer when vibration was present, regardless as to whether it was presented alone or with noise. This appeared to be largely due to a speed-accuracy trade-off when vibration was present. Participants worked faster at the cost of precision after being exposed to vibration. Individuals rated themselves as more alert after the conditions when vibration had been present compared to when it was not present. In an applied situation, this combination of perceived alertness while at the same time exhibiting degraded performance could be a dangerous combination.

Performance effects were found after exposure to vibration and subjective effects were observed after exposure to both vibration and noise; however, the combination of vibration and noise did not produce any additional effects. It has been suggested that synergistic or antagonistic effects may be seen when two environmental stimuli are present simultaneously[26]. Within the present paradigm, no such effects were found. Further, data from our lab collected using the same types of exposures as used in the present study have failed to reveal any cognitive performance degradation during environmental exposure while finding results similar to the present study in regards to subjective ratings[3, 22].

In absolute terms the differences observed between performances after environmental exposures containing vibration and those not containing vibration, while significant, were small. It is worth noting, however, that performance in general was very good. Participants on average had an error rate of around 1.5%, thus even small differences may be of interest. While only exposed for approximately 44 min, the vibration level used in the present study was within the acceptable levels, by European standards, for an 8-hour working day. It is not unusual in many occupations, such as long distance transportation or forestry work, that workers are in fact exposed to this level for a whole working day. Further research is needed on how exposure time affects post-exposure performance, how other types of cognitive functioning are affected, and how long of a recovery time is needed before workers can perform normally again. Large numbers of workers are exposed daily to whole-body vibration. A greater understanding of after-effects and how they may influence safety in the work environment is warranted.

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