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Low Frequency Noise and It's Psychological Effects

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Objective: This entire study has two parts. Study I aimed to develop a psychological assessment scale and the study II aimed to investigate the effects of LFN (low frequency noise) on the psychological responses in humans, using the scale developed in the study I.

Background: LFN is known to have a negative impact on the functioning of humans. The negative impact of LFN can be categorized into two major areas of functioning of humans, physiological and psychological areas of functioning. The physiological impact can cause abnormalities in threshold, balancing and/or vestibular system, cardiovascular system and, hormone changes. Psychological functioning includes cognition, communication, mental health, and annoyance.

Method: 182 college students participated in the study I in development of a psychological assessment scale and 42 paid volunteers participated in the study II to measure psychological responses. The LFN stimuli consisted of 12 different pure tones and 12 different 1 octave-band white noises and each stimulus had 4 different frequencies and 3 different sounds pressure levels.

Results: We developed the psychological assessment scale consisting of 17 items with 3 dimensions of psychological responses (i.e., perceived physical, perceived physiological, and emotional responses). The main findings of LFN on the responses were as follows: 1. Perceived psychological responses showed a linear relation with SPL (sound pressure level), that is the higher the SPL is, the higher the negative psychological responses were. 2. Psychological responses showed quadric relations with SPL in general. 3. More negative responses at 31.5Hz LFN than those of 63 and 125Hz were reported, which is deemed to be caused by perceived vibration by 31.5Hz. 'Perceived vibration' at 31.5Hz than those of other frequencies of LFN is deemed to have amplified the negative psychological response. Consequently there found different effects of low frequency noise with different frequencies and intensity (SPL) on multiple psychological responses.

Conclusion: Three dimensions of psychological responses drawn in regard to this study differed from others in the frequencies and SLP of LFN. Negative psychological responses are deemed to be differently affected by the frequency, SPL of the LFN and 'feel vibration' induced by the LFN.

Application: The psychological scale from our study can be applied in quantitative psychological measurement of LFN at home or industrial environment. In addition, it can also help design systems to block LFN to provide optimal conditions if used the study outcome, .i.e., the relations between physical and psychological responses of LFN.

Keywords: Low frequency noise, Vibration, Psychological effects, Psychological assessment scale

1. Introduction

Low frequency noises (LFN) are referred to as noise with its range from 20 to 200Hz frequency (Bengtsson, Persson, & Kjellberg, 2003). The major causes of LFN are fans, vacuum pumps, compressors, air conditioners, and computer network devices and so on (Berglund, Hassmen, & Job, 1996; Jung, 2011). These systems induce vibration which is hard to be blocked with walls (Hood & Leventhall, 1971; Leventhall, 1988) and they are known to have a negative impact on the functioning of humans. Berglund and Hassmen (1996)'s through literature review identified the impact of LFN on the following functioning of humans; 1) the threshold of sound hearing, 2) balancing and/or vestibular system 3) respiration 4) cardiovascular system 5) hormones 6) cognition 7) communication 8) mental health 9) annoyance 10) sleep, that all can be categorized into two major areas of functioning of humans, physiological and psychological areas of functioning.

Physiological functioning includes threshold, balancing and/or vestibular system, respiration, cardiovascular system, hormones, and sleep. The extended exposure to LFN can change the threshold of sound permanently (von Gierke & Nixon, 1976). Parker (1976) reported the exposure to LFN with high intensity can affect balancing and/or vestibular system and Pedersen, Møller, & Persson (2006) reported LFN can result in physiological symptoms, e.g., headache, dizziness and nausea. Berglund, Hassmen, & Job (1996) suggested LFN can change blood pressure and heart rate though their effect has not been clinically proven yet. Waye, Clow, Edwards, Hucklebridge, & Rylander (2003) reported that the exposure to LFN can cause an increased level of catecholamine and cortisol release and exposed to LFN during sleep can cause a difficulty with deep sleep resulting in tiredness at time of waking up. In sum, physiological impact of the extended exposure to LFN can cause abnormalities in threshold, balancing and/or vestibular system, as well as cardiovascular and, hormone changes in reaction to stress.

Psychological functioning includes cognition, communication, mental health, and annoyance. Møller (1984) measured psychological responses of subjects exposed LFN for three hours while completing various types of tasks. He found the subjects reported experience of annoyance and pressure in the ears during the task completion. Bengtsson, Persson, & Kjellberg (2003) also reported the similar result from the subjects who were interfered by LFN during the task completion and they referred LFN to blocking and annoying compared to the reference noises.

Møller and Lydolf (1984) reported the subjects in their study referred LFN to the sound of diesel engine and further reported experience of headache, insomnia and, difficulty concentrating during exposure to LFN. Many people reported feeling vibration and through vibration of objects or body and complained of interfered daily functioning or annoyance the secondary symptoms such as insomnia, headache, and increased heart palpitation. Møller (1987) measured the level of annoyance by pure tone with their range from 4 to 31.5Hz and he reported a significant increase in annoyance as the sound pressure was increased when measured by pure tone within the range of frequency. Inukai, Taya, Miyano & Kuriyama (1986) measured the psychological responses to pure tones with their ranges from 3 to 40Hz and they found the psychological responses consisted of perception of sound, pressure in the ears, and perceived vibration.

Psychological responses are known to be closely related to physiological responses. Most of the physiological responses are associated with psychological stress, for which LFN, the source of stress, can cause psychological responses that is mainly experienced as annoyance. Therefore, it's necessary to measure both physiological and psychological responses simultaneously to investigate the impact of LFN in humans. As mentioned earlier, physiological responses can be measured through measurement of physiological signals, e.g., hormonal release, blood pressure or heart rate. Psychological responses in general can be measures using psychological assessment scale with multiple items. However, psychological assessment scales used in previous studies were subjectively selected by the researchers and in addition the scale consisted of fewer items, resulting in lack of objectivity and systematic method which then can affect the study results.

Thus we developed an objective psychological assessment scale in the study I and then used it to measure psychological responses along with perceived physiological responses in the study II.

2. Study I: Development of A Multi-dimensional Psychological Scale

The following procedures were used to develop a psychological assessment scale. Words known to be associated with LFN were collected. Soon after presentation of LFN, the participants assessed the appropriateness of the collected words to best describe the psychological responses to presented LFN. Finally, a psychological assessment scale was then finally developed by having participant select most appropriately describing words for LFNs presented to the participants.

2.1 Participants

One hundred eighty two volunteers (104 females and 78 males) with ages from 18 to 29 (20.4 on the average) participated in the experiments. 30 subjects participated in each trial.

2.2 Questionnaire

One hundred noise related items from the Korean adjective dictionary (Park & Kim, 1991) and LFN related articles (Chen & Hanmin, 2004; Leventhall, 2004; Møller, 1984; Persson et al., 2003; Benton & Leventhall, 1986; Poulsen & Mortensen, 2002; Belojevic et al., 2003) were collected. The questionnaire consisted of 100 items of which had 9 subscales each to assess psychological responses. To remove the effect of item order responses, 4 different sets of questionnaire with different order were designed.

2.3 Testing room and noise stimuli

The size of the testing room for LFN was 7.2m x 18m x 2.7m. LFNs consisted of 8 different pure tones and 8 different 1 octave band white noises. Each of them had 4 different levels of frequency (31.5Hz, 63Hz, 125Hz and 250Hz) with sound pressure of 90dB. The stimuli were generated in Adobe Audition (1.0).

2.4 Procedure

Participants were designed to hear LFNs for 30 sec presented through the loudspeaker (Marshall Electronics, INC-S3800S) and they took a 10 second rest before the next LFN presentation. After listening to 8 different LFNs, they evaluated the response on the questionnaire consisting of 100 noise related items. Participants rated the appropriateness of the words to describe each of LFNs on 1 to 9 scale '0' being least appropriate, '9' being most appropriate.

2.5 Results

The mean of the responses of 100 items was obtained, and then all items with the mean score of 6 above were first selected. Then the basic structure was identified on those 100 items and factor analysis was finally conducted to select items for a psychological assessment scale to be used in the study II. The principal axis factoring was used to analyze correlation matrix, a scree plot was used to determine the number of factors and varimax rotation was used to rotate factor structure. Three main factors were extracted. The first factor consisted of 9 items and it referred to "perceived acoustic responses". The second factor consisted of 9 items referred to "perceived physiological responses." The third consisted of 9 items referred to "negative emotion". The number of items of the psychological assessment scale was finally established have 15 out of 33 items that had similar meanings in the appropriateness. As the result, 4 items from "perceived psychoacoustic characteristics", 4 from "perceived physiological characteristics" and 9 from "negative emotion" were finally selected shown in Table 1.

Table 1. 17 items in the psychological assessment scale

Perceived psychoacoustic characteristics	Perceived physiological characteristics	Negative emotion
Sound deep, Sound thick, Sound loud, Feel vibration	Ear hurting, Headaching, Nauseating, Dizzy	Annoying, Unpleasant, Stressful, Irritable, Noisy, Choking Anxious, Interfering, Weird

3. Study II: Effect of LFN on Psychological Responses

The laboratory experiment was conducted to evaluate psychological responses in response to LFN.

3.1 Participants

42 paid volunteers (15 females and 27 males) with ages from 19 to 26 (22.4 on the average) participated in the experiments. 30 volunteers participated in each trial in the experimental chamber.

3.2 Experimental room and noise stimuli

The experimental chamber was a soundproof chamber with its size of 3 x 5 x 2.65 meters. A specially designed LFN loudspeaker (Marshall Electronics, INC-S3800S) was installed to present the LFNs. LFNs consisted of 12 different pure tones and 12 different 1 octave band white noises with 4 different frequency (31.6Hz, 63Hz, 125Hz, and 250Hz), and each frequency has 3 different sound pressure level (50, 70, and 90 phon). As shown in the Table 2. The LF stimuli were generated using Adobe Audition (1.0).

Table 2. Noise stimuli used in this experiment

	31.5Hz	63Hz	125Hz	250Hz
50 phon	94dB	91dB	90dB	90dB
70 phon	85dB	80dB	77dB	73dB

3.3 Psychological assessment scale

The psychological assessment scale consisting of 17 items developed in the study I was used. And the participants were instructed to rate on their response on a 1-7 scale ('1' being least likely and '7' being most likely).

3.4 Procedure

3 participants completed the experiment in each trial. They were presented LFN for 30 sec and then they were to rate their responses on each of 17 items of the psychological assessment scale. There were 90 seconds of rest periods between LFN presentations. Participants were instructed to assess their responses to the stimuli during this resting period. The order of LFN presentation was counterbalanced by the group with 3 subjects.

3.5 Results

3.5.1 Pure tone

The psychological responses to different frequencies and SPL of LFN are shown in Figures 1, 2, 3. To test statistically significant differences by frequency and SPL in psychological responses, two-way repeated measures ANOVA was conducted. To test patterns of changes in psychological responses by increases of frequency and SPL, trend analysis was administered.

The results indicated the psychological responses to 'sound thick' and 'sound dull' among perceived physical responses showed a linear relation with frequency. (F=85.774, p<.001; F=72.728, p<.001) and also showed a linear relationship with SPL (F=60.554, p<.001; F=54.987, p<.001). That is, the lower the frequency of LFN and the SPL higher were, more thick and dull the sound felt.

Responses to perceived vibration showed linear and quadric relations with frequency (linear F=31.258, p<.001, quadratic F=

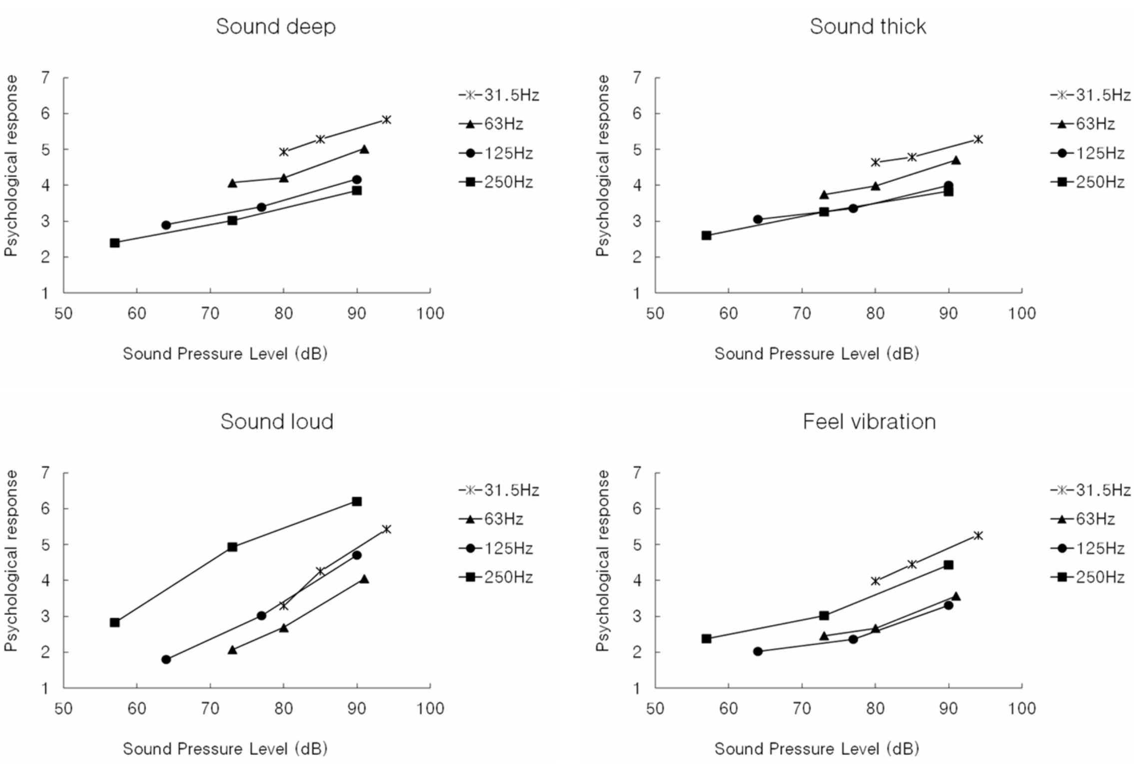

Figure 1. Example of responses on perceived psychoacoustic characteristic factor (pure tone of LFN)

65.904, p<.001), and also showed linear and quadric relations with SPL. That is, psychological response, 'perceived vibration' was the highest at 31.5Hz, lowest at 63Hz, and 125Hz, and higher again at 250Hz. There was little difference in 'perceived vibration' between the stimuli from 50 phon to 70 phon, while a bigger difference was found between the stimuli of 70 to 90 Phon. 'Sound loud' showed a quadratic relation with frequency (F=129.426, p<.001) yet a linear relation with SPL (F=337.828, p<.001), which means sound was perceived loud at 250Hz and 31.5Hz but perceived relatively low as shown in Figure 1.

Perceived psychological responses, 'ear-hurting', 'headache', 'feel dizzy' showed quadric relations (both p<.001), but linear relations with SPL (both p<.001), that is, greater values at 250Hz and 31.6Hz but low values at 63Hz and 125Hz shown in Figure 2. Psychological responses associated with negative emotions showed a quadric relation with frequency (both p<.001), but linear relations with SPL (both p<001). Responses, feel annoyed and feel stressed showed a lowest value at 125Hz, higher at 31.5Hz, and highest at 250Hz in order shown in the Figure 3.

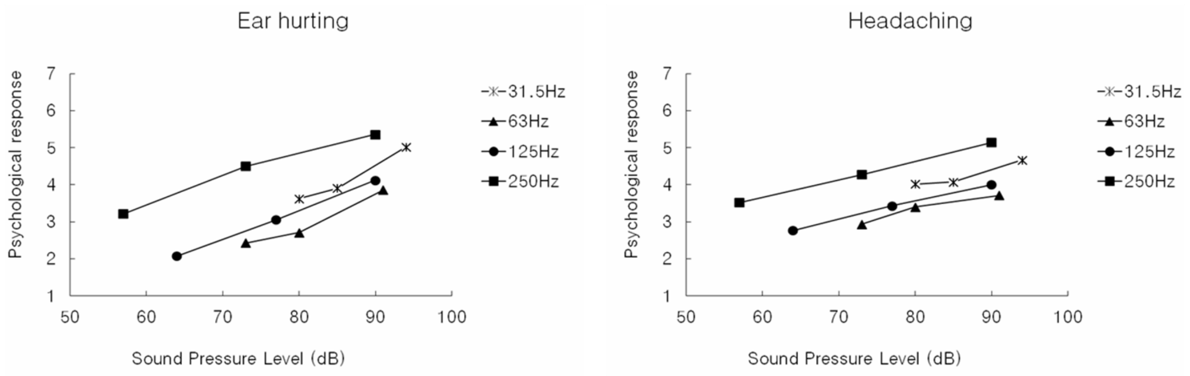

Figure 2. Example of responses on perceived physiological response factor (pure tone of LFN)

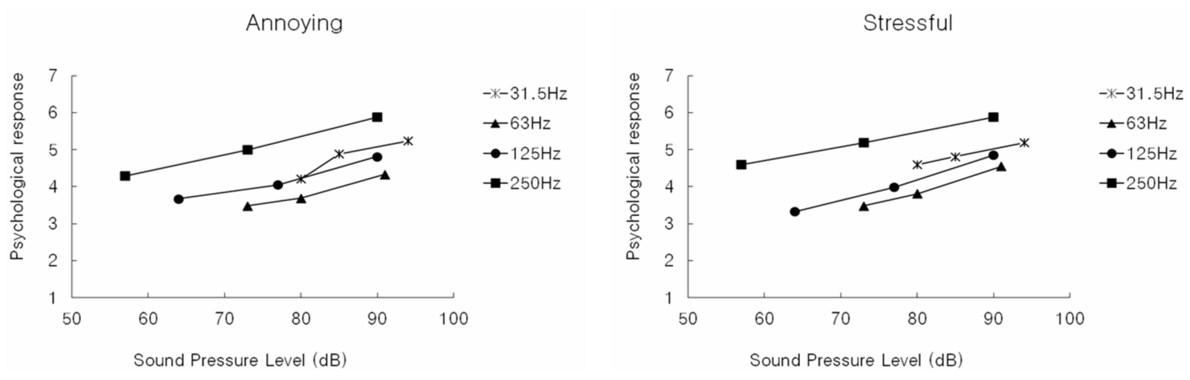

Figure 3. Example of responses on the negative emotion factor (pure tone of LFN)

3.5.2 One octave band white noise

To investigate similarities between one octave band white noise and pure tone, Pearson's correlation coefficient between psychological responses to both of them was calculated. And a difference in means between psychological responses to pure tone and one octave band white noise was tested using repeated measures ANOVA. The results showed the correlation coefficient of 17 psychological responses ranging from .76 ('feel stressed') to .98 ('sound dull'), which indicates a high correlation between them that suggests a similar psychological response pattern between one octave band white noise and pure tone. A test to identify a difference in the means of psychological responses between the two different stimuli showed a slightly higher mean in 'perceived vibration' to pure tone ($p<.01$), a higher mean in 'feel weird' and 'feel anxious' to one octave band white noise ($p<.01$, $p<.05$). No difference in the means among the rest of 14 psychological responses ($p>.05$).

3.5.3 Regression analysis on annoyance

The frequencies of LFNs and their psychological responses showed quadric relations in general. These results are deemed to be associated with unique psychological responses to 31.5Hz LFN, which may have the highest responses of 'perceived vibration' at 31.5Hz. Inukai et al. (1986) reported that perceived vibration have caused 'unpleasantness and annoyance' and Ochiai (1999) reported perception of vibration reached the highest at the ranges of 30 to 50Hz. This then suggests that 'perceived vibration' may have a direct impact on perception of negative emotions.

To test this possibility, a hierarchical regression analysis was conducted as shown in Table 3. The model I tested the effect of the frequency and SPL on annoyance and the model II tested the effect of the frequency, SPL, and 'perceived vibration' on 'feel annoyed.' The results showed its R2 of the Model I as .742 and that of the Model II .971. The effect of perceived vibration on annoyance turned out to be .230 ($p<.001$), which suggests a statistically significant difference between the values of two R2 values. This means that perceived vibration induced by LFN as well as the frequency and SPL of LFNs have impact on annoyance. The effect of 'feel vibration' turned out to have an impact not only on perceived loudness of the noises but on 'feel stressed'.

Table 3. Hierarchical regression analysis on annoyance

		B	Std. Error	T	P	R2
Model 1	Constant	-0.541	1.028	-0.526	.611	0.742
	Frequency	0.006	0.002	3.873	.004	
	SPL	0.054	0.012	4.612	.001	
Model 2	Constant	0.749	0.397	1.889	.096	0.971
	Frequency	0.006	0.001	10.484	.000	
	SPL	0.016	0.006	2.501	.037	
	Vibration	0.537	0.067	8.020	.000	

4. Conclusion

This study aimed to first develop a psychological assessment scale to measure psychological responses to LFN and then used it to measure psychological responses to LFN. The developed psychological scale has 17 items consisting of 3 dimensions of the perceived responses to LFN, i.e., perceived physical characteristics, perceived psychological characteristics, and negative emotions. This assessment scale differs from those of others (Leventhal, 2004; Moller & Lydolf, 2003) in that this assessment scale was developed in a more systematized and objective method.

Inukai et al. (1986) measured psychological responses and identified 3 dimensions, perception of sound, pressure in the ears, and vibration. The scale we developed and used in our studies compared to Inukai's scale included more items on perceived physiological responses and negative emotions. The different results observed in this study when comparing to those of Inukai et al. (1986) is deemed to be induced by different frequencies used in the studies because Inukai et al. (1986) used 3-40Hz of LFN, while this study used 31.5-250Hz.

Three dimensions of psychological responses drawn in this study differed from others by frequencies and SLP of LFN. Psychological responses showed a linear relation with SPL, that is the higher the SPL was, the higher the negative psychological responses were. Psychological responses showed quadric relations in general. More negative responses at 31.5Hz compared to those of 63 and 125Hz were observed, which is possibly because of perceived vibration by 31.5Hz. Perceived vibration at 31.5Hz compared to those of other frequencies of LFN is deemed to have amplified the negative psychological response. Consequently, negative psychological responses are deemed to be affected by the frequency, SPL and subjectively perceived vibration by participants to the stimuli. This developed psychological scale from our study can be applied in quantitative measurement of LFN at home or in industrial environments. In addition, it can also help design systems blocking LFN to provide optimal conditions if used our study outcome, the relations between physical and psychological responses of LFN.

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