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Characterizing perceived aspects of adverse impact of noise on construction managers on construction sites

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ABSTRACT

This study aims to assess various perceived adverse effects of noise on construction sites according to the different stages and machinery used in the stages, and to examine whether or not personal-situational factors affect the judgment of managers regarding the adverse impact of noise at work through a self-reported survey method. Four primary construction stages and twenty-four types of construction machines were evaluated. The effects of personal (noise sensitivity) and situational (types of jobs, and years of working) factors on the adverse impacts of noise on annoyance, work performance, work safety, and speech interference at work were examined. The results show significant differences in perceived noise annoyance in the various construction stages. The demolition stage is the most annoying, followed by the foundation, earthwork, and concrete framing stages. In addition, the annoying equipment differs for each construction stage. A breaker, pile driver, and hammer compactor are rated as the most annoying construction machines in the demolition, foundation, and earthwork stages, respectively. Individual noise sensitivity appears to have the most significant influence on the adverse impacts of noise on annoyance, work performance, work safety, and speech interference. A high noise sensitivity group tends to judge construction noise to be more adverse than the rest. In addition, different interrelationships between the adverse items of noise are found across their types of jobs: building construction, civil construction, and safety management. The findings of this study will provide further knowledge to facilitate better noise management planning on construction sites.

1. Introduction

Construction activities generate high levels of noise. Workers on construction sites are exposed to potentially hazardous noise levels [1–3]. It has been reported that noise levels at construction sites range from 80 to 120 dBA depending on the type of construction activities [2,4]. As noise generated by construction activities can easily exceed the occupational safety and health administration limit of 90 dBA, construction industry workers suffer more from the adverse effects of noise than other trades [5]. However, compared to other types of environmental noises such as road, traffic, airplane, and train noises, relatively few studies have been conducted on the adverse impacts of construction noise [1–7] because construction noise is usually difficult to predict owing to constant changes in location, various sizes of construction sites, and the transience of the work force [2,3,8].

Construction noise typically has various acoustic characteristics such as steady noise, fluctuating noise, intermittent noise, quasi-steady impulsive noise, and isolated bursts of sound energy that depend primarily on the types of construction machines in use [7]. In particular, the tasks at construction sites are constantly changing during the construction stages [6,8], and each task uses different equipment [3,7]. In addition, as tasks often overlap, construction noise is composed of complex combinations of noise sources, resulting in a high variability in the noise [7]. Some have reported that different combined construction noises result in varying annoyance levels [7,9]. All of the above indicate that construction noise is not only as hazardous as any other type of noisy environment, but far more difficult to control.

In this context, a number studies have focused on construction task-based approaches to collect noise exposure data [1,3,5,10]. The approach based on the physical measurement of noise levels is useful for describing the noise exposures of construction workers, however, it provides limited information on how the construction workers perceptually understand the construction noises [11,12]. It has been reported that noise levels often do not provide a clear picture of how a

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construction worker perceives construction noises [7]. This demonstrates that it is important to assess the subjective adverse impacts of noise on workers at construction sites in terms of various construction tasks and machines.

In general, subjective adverse effects of noise, which include annoyance, disturbance, and speech interference, have been investigated in previous studies [13–16]. Noise annoyance is a key descriptor of environmental noise, which is acknowledged as a multifaceted concept associated with acoustic and non-acoustic factors [17]. Some studies have also indicated that noise affects work safety in workspaces, which results in an increase in the number of errors at work [18,19]. Additionally, noise critically affects speech comprehension. Noise interference with speech comprehension results in problems with concentration, decreased working capacity, and stress reactions at work [20,21]. Many respondents have reported that noise exposure worsens work performance [22–24].

These subjective adverse effects of noise are influenced by both acoustic and non-acoustic factors [17]. There are various non-acoustic factors influencing subjective responses to noise. Numerous studies have proven that personal and situational factors affect responses to noise [13,17,25]. Personal factors affecting noise evaluation include information such as age, gender, education level, and noise sensitivity [13]. Situational factors such as the length of residency, previous experience with the area, or the type of area also affect reaction to noise [17,25]. There are various types of workers in the construction field (e.g., construction managers, carpenters, laborers, and roofers); each worker is characterized by unique personal factors. Hence, it is necessary to investigate the effects of these personal factors, in addition to situational factors, on the adverse impact of noise [13,26]. According to most of the previous studies on personal factors of noise evaluation, the effects of gender, age, and education level on noise annoyance are not significant [13,16]. However, the noise sensitivity of individuals has been reported as one of the critical individual factors in the determination of reaction to noise [13,27–29]. This implies that self-reported noise sensitivity can also be an important personal factor for construction managers. In terms of work environment, task characteristics, type of work, and working experience have been considered as situational factors in previous studies [10,30,31]. In the context of construction industry, years of working and major jobs in a construction site can be considered as situational factors of construction workers that affect the judgment of adverse effects of construction noises on sites. For instance, the degree of adverse impact of noise might differ according to primary jobs at construction sites, and years of working for construction managers might affect the perception of noise due to adaptation to noise.

According to the Korean Standard Classification of Occupations [32], workers at construction sites can typically be classified into three groups: unskilled workers, equipment operators/skilled workers, and managers. Unskilled workers are general site labor with little or no construction qualifications, and construction equipment operators or skilled workers typically perform the actual construction work with extensive knowledge and experience in their craft or profession [10]. The roles of construction managers include developing a work schedule and strategy to complete the project and ensuring that the construction site will pass safety inspections [33]. Construction managers communicate with a range of people including clients, subcontractors, suppliers, the public, and the workforce on site. Construction noise studies have mainly focused on the noise exposure of equipment operators and construction workers such as carpenters, laborers, ironworkers, roofers, and operating engineers [2,3,5,10,34] but only a few studies on construction managers on site have been conducted [35,36]. The construction equipment operators and workers are typically self-employed so once they are done with their specific tasks, they leave the construction sites. However, as construction managers are coordinating and managing all on-site construction activities in accordance with the construction project schedule, they could provide more precise and comprehensive information perceptions of construction noise and the adverse impacts of noise at work. In this sense, the present study focuses on noise perception of construction managers.

This study aims to assess annoyance of noise at construction sites according to the different construction stages and machinery used in the stages, and to investigate personal (individual noise sensitivity) and situational (type of job and years of working) factors of construction managers that significantly contribute to the subjective adverse impacts of noises at construction sites. Specifically, four hypotheses were formulated:

(1) Perception of noise annoyance will differ in terms of different construction stages and machine types.
(2) Individual noise sensitivity of a construction manager will affect subjective adverse impacts of noise.
(3) Type of job of a construction manager will affect subjective adverse impacts of noise.
(4) Years of working in a construction industry will affect subjective adverse impacts of noise.

To examine these hypotheses, a social survey was conducted for construction managers who currently work at construction sites. Based on the survey results, this study discusses noise control measures considering construction tasks and the personal/situational factors of the construction managers.

2. Method

2.1. Survey participants

The survey was performed at a Korean construction company, the fourth largest construction company in Korea, conducting various civil, building, plant, and housing projects in the domestic and overseas markets. According to the annual report of the company [37], the construction company employed 5,846 full-time employees. Out of them, 3,148 construction managers are currently working in the company. The survey was conducted in the annual training session held in the training institute of the company; 1,122 out of 3148 construction managers were randomly selected to participate in the annual training. The survey participants were randomly selected from the construction managers who attended the annual training sessions for construction managers in the company. The survey was given to 500 out of 1,122 managers; 461 respondents finished their questionnaire. In addition, 92.2% respondents completed their survey, and this value is 14.6% of total construction managers in the company. The study was approved by the local research ethics committee and informed written consent was obtained from all respondents after fully explaining to them the nature, purpose, and procedures used for the study.

Table 1 summarizes the survey response data with respect to years of experience, gender, age, and primary tasks of the respondents. Because of the occupational characteristics of the construction managers, 98.5% of the respondents were male and 1.5% were females. In terms of year of experience, 65.1% of the respondents had less than 10 years working experience, and the balance of the respondents more than 10 years. Regarding the primary tasks at construction sites, the bulk of the respondents worked in civil (50.8%) and building engineering (31.2%), followed by safety management (14.5%).

2.2. Questionnaire

The survey questionnaire comprised items related to 1) personal and situational factors of participants, 2) adverse impacts of construction noise including construction stages and machines, and 3) self-reported adverse impact of construction noise at work.

Table 1
Descriptive statistics of the survey participants. Numbers in years of experience, gender, and type of job indicate the number of respondents and percentage of respondents in each category of the column. Numbers in age indicate mean age and standard deviation in each category of column.

Year of working, N (%)	Total 461 (100%)	5 yrs > 120 (26.0%)	5–10 yrs. 180 (39.0%)	10–15 yrs. 91 (19.7%)	15 yrs < 70 (15.3%)
Gender					
Male, N (%)	454 (98.5%)	115 (95.8%)	178 (98.9%)	91 (100.0%)	70 (100.0%)
Female, N (%)	7 (1.5%)	5 (4.2%)	2 (1.1%)	0 (0.0%)	0 (0.0%)
Age, Mean (SD)	35.7 ± 5.1	30.6 ± 2.4	34.3 ± 2.8	38.8 ± 2.4	43.9 ± 2.5
Type of job					
Building, N (%)	144 (31.2%)	45 (37.5%)	72 (40.0%)	23 (25.3%)	4 (5.7%)
Civil, N (%)	234 (50.8%)	60 (50.0%)	78 (43.3%)	44 (48.4%)	52 (74.3%)
Safety, N (%)	67 (14.5%)	14 (11.7%)	26 (14.4%)	21 (23.1%)	6 (8.6%)
Others, N (%)	16 (3.5%)	1 (0.8%)	4 (2.2%)	3 (3.3%)	8 (11.4%)

2.2.1. Personal and situational factors

Similar to previous studies [38–42], the self-reported noise sensitivity of participants was assessed using a single response to the following question: "*How would you rate your sensitivity to noise on an 11-point scale?*" (0: not at all sensitive and 10: extremely sensitive).

As situational factors of the respondents, years of experience and major jobs in a construction company were also collected during the survey. According to a previous study [43], years of experience in a construction industry was assessed with the following response alternatives: 1) less than 5 y, 2) 5–10 y, 3) 10–15 y, and 4) more than 15 y. The participants were asked to list their primary jobs at a construction site from four categories: 1) building construction, 2) civil construction, 3) safety management, and 4) others (e.g., administration work).

2.2.2. Adverse impacts of construction stages and machines

2.2.2.1. Type of construction stages. In this study, construction work was categorized into five stages: demolition, foundation, earthwork, concrete framing, and others (pavement, interior, or exterior finishes). In the demolition stage, the primary tasks are the tearing down of buildings and other man-made structures before constructing new buildings or civil structures. Foundation work includes the design of foundation elements of structures. Earthworks are engineering works using quantities of soil or unformed rocks, and includes the excavation, transport, placement, and compaction of fill materials during construction. Concreting work comprises a variety of tasks, including the building of columns, beams, slabs, floors, and other reinforced concrete structures. The participants were asked to choose one construction stage that was the most annoying stage among the five construction stages based on their working experience at construction sites with the following question: "*Please choose a stage that produces the most annoying noise among the following five construction stages.*" According to ISO/TS 15666 [44], noise-induced annoyance was defined as "one person's individual adverse reaction to noise in various ways including dissatisfaction, bother, annoyance and disturbance" to the survey respondents.

2.2.2.2. Types of construction machines. Various types of equipment are operated for building and civil construction, and these machines have different noise characteristics. As shown in Fig. 1, a total of 24 construction machines were listed in the questionnaire. Table 2 presents the measured noise levels of 24 construction machines, adapted from previous studies, as well as the classification of the temporal variability of each machine's noise. According to ISO 2204 [45], the temporal characteristics of noise can generally be divided into steady and non-steady noise. Steady noise is noise that exhibits relatively low temporal variation (e.g., air compressor and asphalt finisher). Non-steady noise can be subdivided into fluctuating noise (e.g., concrete plant and concrete mixer), intermittent noise (e.g., gang-form demolition and demolition machines), and impulse noise, of which the latter may refer to either discrete impulse noise (e.g., hammer machine and pistol) or quasi-steady impulse noise (e.g., breaker and jack hammer). The participants were asked to select the machines that they felt were the most annoying during each of the five construction stages with the following question: "*In the listed 24 construction machines, choose machines at each construction stage that produce the most annoying noise.*" The participants were allowed to choose multiple construction machines in each construction stage.

2.2.3. Subjective assessment of adverse impacts of construction noise at work

In this study, four adverse impacts of noise (annoyance, work performance, work safety, and speech interference) that are associated with subjective effects in the workplace were selected to assess the perceived adverse effects of noises at construction sites.

Noise annoyance was assessed with the following question: "*Thinking about the last (*12 months *or so), evaluate the noise annoyance when you are working at a construction site.*" The adverse effect of noise on work performance was evaluated using the following question: "*Thinking about the last (*12 months *or so), evaluate the adverse effect of noise on work performance when you are working at a construction site.*" The effect of noise on work safety was assessed using the following question: "*Thinking about the last (*12 months *or so), evaluate the adverse effect of noise on your work safety when you are working at a construction site.*" The speech interference was evaluated with the following question: "*Thinking about the last (*12 months *or so), evaluate the adverse effect of noise on speech communication with your coworkers when you are working at a construction site.*" According to the ISO/TS 15666 [44], the participants were asked to evaluate the degree of the adverse impacts of noise of the four items listed above based on their working experiences at construction sites by using an 11-point numerical rating scale (0: not at all and 10 extremely).

2.3. Data analysis

All statistical analyses were performed using a statistical software package, SPSS (version 23.0, IBM, USA). The percentage of the responses to adverse construction stages and machines were calculated. Analysis of variance (ANOVA) tests were conducted to examine the differences in subjective assessments according to the personal and situational factors of the respondents. In all ANOVA tests, post-hoc comparisons were conducted using the Tukey's Honest Significant Difference (HSD) test for multiple comparisons. Spearman's rank correlation coefficient among the adverse impacts of noise for each independent group (noise sensitivity, main jobs, and years of working) was calculated to explore relationships between the adverse impacts of noise and to compare the coefficients regarding independent groups. The correlation coefficients retrieved from different groups were tested against each other using Fisher's z transformation [50,51]. Lastly,

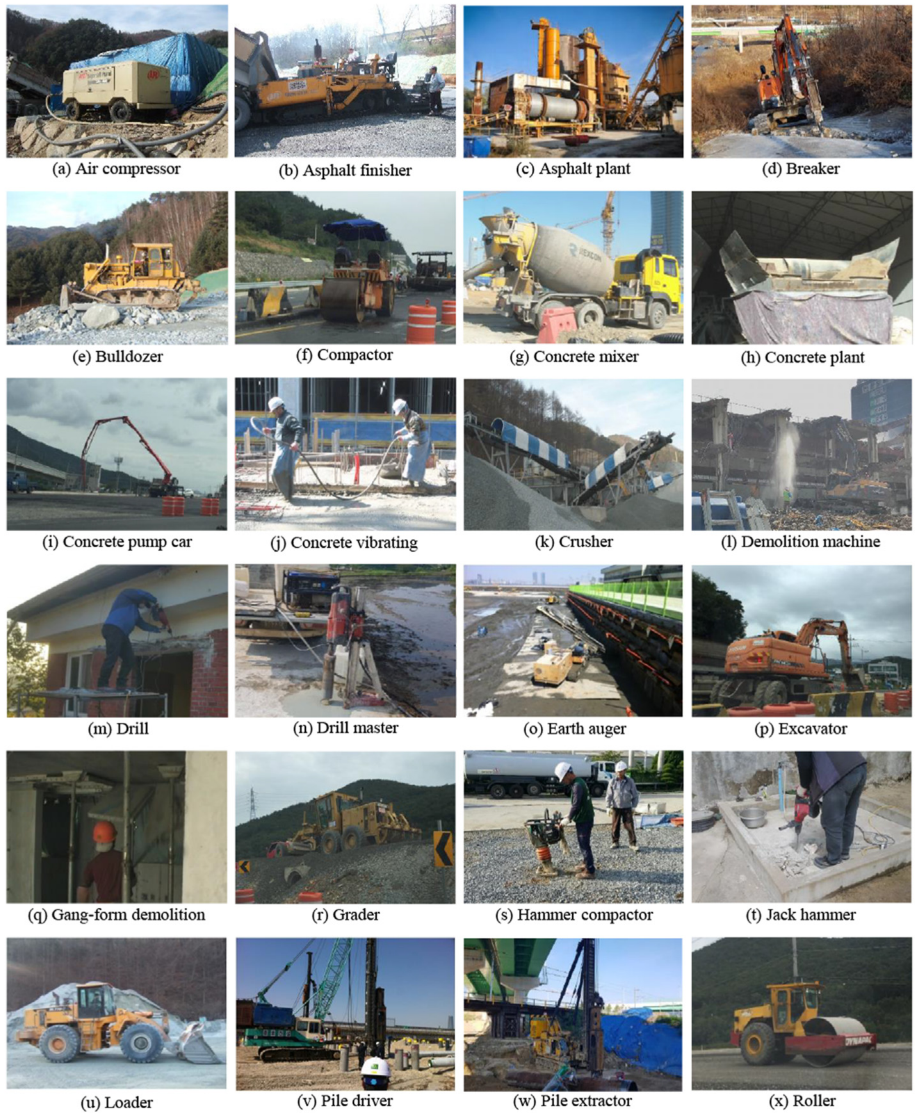

Fig. 1. Twenty-four construction machines.

multiple regression analyses with all independent variables (noise sensitivity, type of job, and years of working) based on dummy variables were conducted to estimate their effects on the subjective adverse impacts of noise at construction sites.

3. Results

3.1. Annoying construction stages and machines in terms of noise

This section discusses the adverse effects of construction noise in terms of construction stages and machines. The construction stage rated the most annoying is first evaluated and construction machines that contributed to the annoyance are examined.

3.1.1. Annoying construction stages

Respondents selected the construction stage they considered to be the most annoying. The results showed that the demolition stage was rated as the most annoying stage with 60.7% of the total responses, followed by the foundation stage with 23.6% of the total responses, earthworks (8.7%), and concrete works (6.1%). Less than 1% of the participants selected the other construction stages (e.g., construction finishing or pavement stage) as the annoying construction stage.

3.1.2. Annoying construction machines

The percentage for each construction machine that the participants selected as the most annoying construction machine at each construction stage was calculated. Fig. 2 shows the percentages of the most annoying of the 24 construction machines in the four construction stages (demolition, foundation, earthwork, and concrete construction). It was found that the primary noise sources differ across the four construction stages as the primary tasks of each stage differ.

In the demolition stage, the bulk of the respondents identified the breaker as the most annoying machine (61.3%), followed by the demolition machine (9.3%) and gang-form demolition (9.0%). During foundation work, construction managers rated the pile driver as the most annoying piece of construction equipment with 42.2% of the total responses. Participants selected the hammer compactor (20.5%) and excavator (15.4%) as the primary noise sources during the earthwork stage. In the concreting stage, the concrete pump car was rated as the most annoying noise source (35.7%).

3.2. Effects of personal factors on noise impact at work

In this section, the self-reported adverse impacts of construction noise on annoyance, work performance, work safety, and speech interference for construction managers are analyzed. In particular, the

Table 2
Construction equipment noise level measured 15 m away from the source and classification of noise in terms of temporal variability (steady, fluctuating, intermittent, discrete impulse, or quasi-steady impulse noise) according to ISO 2204.

Name of machine	Noise level (L_{eq}, dBA)	[Refs.]	Classification of noise
(a) Air compressor	81.0	[46]	Steady
(b) Asphalt finisher	76.5	[47]	Steady
(c) Asphalt plant	88.3	[48]	Fluctuating
(d) Breaker	88.7	[47]	Quasi-steady impulse
(e) Bulldozer	75.8	[47]	Fluctuating
(f) Compactor	82.0	[46]	Fluctuating
(g) Concrete mixer	62.5	[47]	Fluctuating
(h) Concrete plant	72.8	[47]	Fluctuating
(i) Concrete pump car	73.5	[47]	Fluctuating
(j) Concrete vibrating	68.3	[47]	Fluctuating
(k) Crusher	85.6	[48]	Fluctuating
(l) Demolition machine	65.9	[47]	Intermittent
(m) Drill	80.9	[47]	Steady
(n) Drill master	86.8	[47]	Steady
(o) Earth auger	76.6	[47]	Steady
(p) Excavator	76.5	[47]	Fluctuating
(q) Gang-form demolition	105.0	[49]	Intermittent
(r) Grader	72.7	[47]	Fluctuating
(s) Hammer compactor	77.4	[47]	Fluctuating
(t) Jack hammer	88.0	[46]	Quasi-steady impulse
(u) Loader	75.6	[47]	Fluctuating
(v) Pile driver	89.2	[47]	Discrete impulse
(w) Pile extractor	81.9	[47]	Discrete impulse
(x) Roller	70.6	[47]	Fluctuating

differences in the self-reported adverse impacts in terms of personal (noise sensitivity) and situational (types of jobs and years of working in the construction industry) are examined based on the survey responses.

3.2.1. Effect of noise sensitivity

Similar to previous studies [16,27], the participants were divided into three groups based on their standardized noise sensitivity rating score and cumulative probability: 0–32%, 33–66%, and 67–100% corresponding to high-sensitivity (HS), medium-sensitivity (MS), and low-sensitivity (LS) groups, respectively. This approach is useful for dividing the groups with a relative indicator for noise sensitivity within the participants. Additionally, regarding an absolute indicator for noise sensitivity, all participants grouped into "MS" (n = 100) had a self-reported noise sensitivity of "5," which indicates "moderate noise sensitivity" level on the 11-point numerical rating scale. The mean sensitivity rating scores of "LS" (n = 181) and "HS" (n = 165) were 3.1 (SD = 1.0) and 7.2 (SD = 1.0). In addition, there were significant mean differences among the three noise sensitivity groups ($F_{2,\ 458} = 956.84$, $p < 0.001$), demonstrating that the participants were ideally divided into three noise sensitivity groups with respect to both relative and absolute indicators of noise sensitivity.

The mean rating scores for the self-reported adverse impacts of construction noise in terms of the three noise sensitivity groups are plotted in Fig. 3. It was found that there are significant differences in the adverse impacts of noise according to the noise sensitivity groups. Overall, the mean rating scores of the HS group for four adverse impacts of noise were the highest, followed the MS and LS groups. One-way ANOVAs were conducted for four adverse impacts of construction noises in terms of the noise sensitivity groups. The ANOVA results show that the main effect of noise sensitivity was statistically significant across the four adverse impacts of noise: annoyance ($F_{2,\ 452} = 11.47$, $p < 0.001$) work performance ($F_{2,\ 452} = 33.76$, $p < 0.001$), work safety ($F_{2,\ 452} = 26.78$, $p < 0.001$), and speech interference ($F_{2,\ 452} = 27.75$, $p < 0.001$). Tukey HSD post-hoc tests revealed that participants grouped into HS reported construction noises to be more adverse than those in the MS and LS groups at 0.01 significance level.

In addition, the LS group exhibited significantly lower scores with regard to adverse impacts on work performance ($p = 0.003$), work safety ($p = 0.004$), and speech interference ($p < 0.001$) compared with the MS group. There was no significant difference between the LS and MS groups with regard to noise annoyance ($p = 0.90$). These results

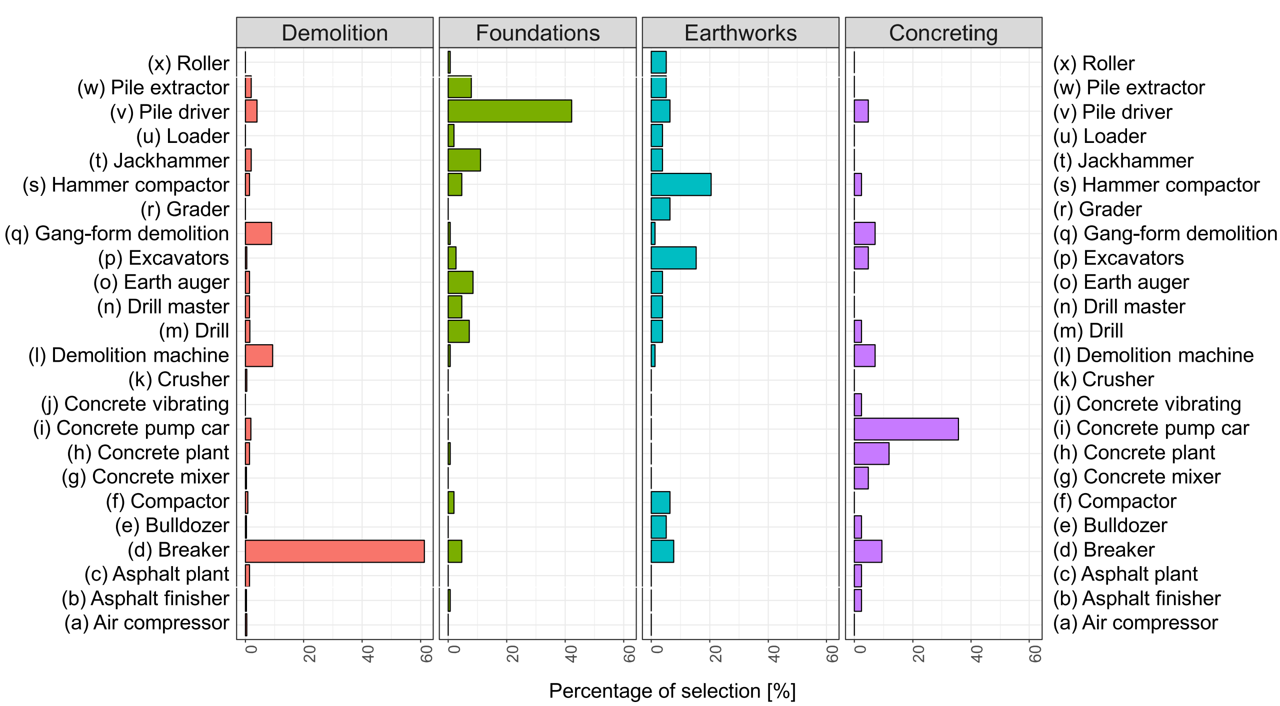

Fig. 2. Percentage of each construction machine selected as the most annoying machine at each construction stage.

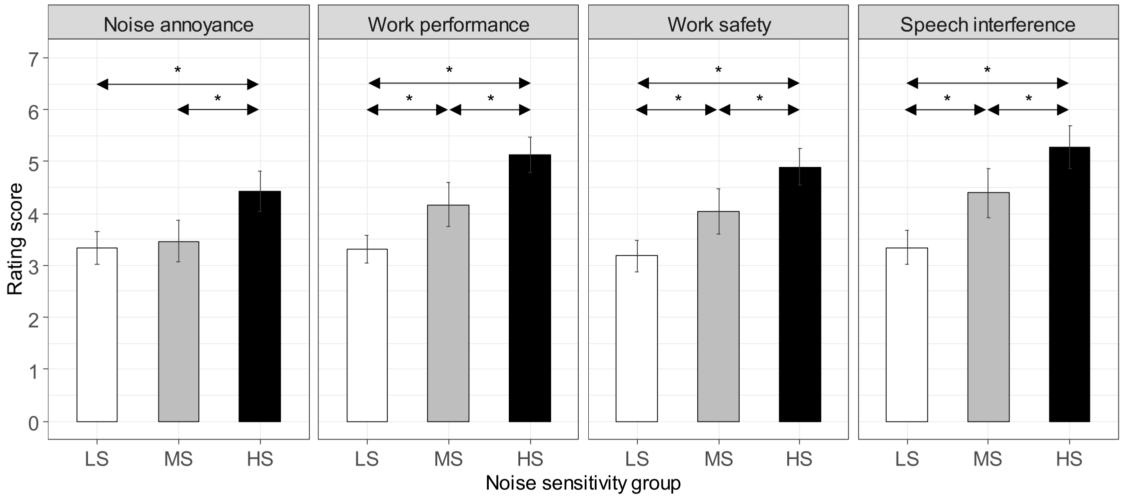

Fig. 3. Mean rating scores of self-reported adverse impacts of noise on noise annoyance, work performance, work safety, and speech interference in construction sites according to noise sensitivity groups (LS, MS, and HS). Error bars indicate 95% confidence intervals, and asterisks indicate statistically significant differences in mean rating scores between groups according to Tukey's HSD post-hoc test (*$p < 0.05$).

indicate that noise sensitivity of construction managers could be a critical personal factor influencing the adverse impact of noise at construction sites.

To explore the differences in relationships between the adverse impacts of noise regarding noise sensitivity groups, Spearman's correlation coefficients were calculated. Table 3 presents the correlation coefficients among the adverse items affected by construction noise (annoyance, work performance, work safety, and speech interference) in terms of the three noise sensitivity groups.

Although all adverse items are significantly correlated, the strength of correlations are different across the three noise sensitivity groups. The correlation coefficients among the four adverse impacts of noise were compared across the three noise sensitivity groups based on Fisher's z transformation. The results showed that the correlation coefficient between work performance and work safety for the LS group was significantly smaller than those for MS ($p = 0.006$) and HS ($p = 0.001$) groups. In addition, relatively stronger correlations between work performance and speech interference were found in the HS group than in the LS group ($p = 0.008$). These findings indicate that the correlation between work performance and other adverse items of noises strengthens as individual noise sensitivity increases.

3.2.2. Effect of types of jobs and years of working in a construction industry

To investigate the effects of the primary jobs of participants at construction sites, the mean rating scores of adverse items of noise are plotted for three primary jobs (building construction, civil construction, and safety management), as shown in Fig. 4. Other types of jobs, such as administration, were not considered as only 16 participants (3.5%) were categorized into other types of jobs as presented in Table 1. A one-way ANOVA was performed to examine the statistical mean differences in the adverse impacts among types of jobs at a construction site. The ANOVA results showed that the effects of types of main job were not statistically significant in annoyance ($F_{2,\ 436} = 0.57$, $p = 0.57$), work performance ($F_{2,\ 436} = 1.57$, $p = 0.21$), work safety ($F_{2,\ 436} = 1.98$, $p = 1.39$), or speech interference ($F_{2,\ 436} = 1.65$, $p = 0.19$). This indicates that types of jobs of construction managers do not affect the mean values of self-reported adverse impacts of noise on construction sites.

However, it was found that there were differences in correlations between the four adverse impacts of noise regarding the types of primary jobs as listed in Table 4. Overall, the respondents in civil construction and safety management exhibited relatively higher correlations between the four adverse impacts of noise than those for building construction.

The correlation coefficients among the four adverse impacts of noise were compared in terms of three different types of job using Fisher's z transformation. The results revealed that correlations between noise annoyance and the other adverse items (work performance, work safety, and speech interference) for the building construction group were significantly lower than for the civil construction and safety management groups at a 0.01 significance level. In addition, it was found that civil construction managers exhibited significantly greater correlations between the adverse impacts of noise on work safety and work performance (ρ = 0.80) than building construction managers (ρ = 0.64) at a 0.01 significance level. These results for comparing correlation coefficients also showed that construction managers in the safety management group exhibited a significantly greater correlation between work safety and speech interference (ρ = 0.88) compared to those in building (ρ = 0.68) and civil construction (ρ = 0.81) at 0.01 and 0.05 significance levels, respectively. The comparisons of the correlation coefficients between the groups demonstrate that the interrelationships between the adverse impacts of noise can be influenced by the primary jobs and tasks of construction managers. Although no significant differences were found in the mean rating scores for each adverse item regarding various jobs from the ANOVA tests.

Fig. 5 shows the mean rating scores of adverse impacts of noise on four items in terms of years of working in a construction company. The ANOVA results showed that the effect of the working years of the participants is not statistically significant for annoyance ($F_{3,\ 451} = 0.39$,

Table 3
Spearman's rank correlation coefficients among adverse impacts of noises with three noise sensitivity groups. Low sensitivity (LS): n = 181, Medium sensitivity (MS): n = 100, and High sensitivity (HS): n = 165.

	Noise sensitivity	Work performance	Work safety	Speech interference
Noise annoyance	LS	0.48**	0.53**	0.41**
	MS	0.46**	0.47**	0.44**
	HS	0.53**	0.49**	0.50**
Work performance	LS		0.60**	0.55**
	MS		0.77**	0.61**
	HS		0.78**	0.70**
Work safety	LS			0.73**
	MS			0.67**
	HS			0.80**

**$p < 0.01$.

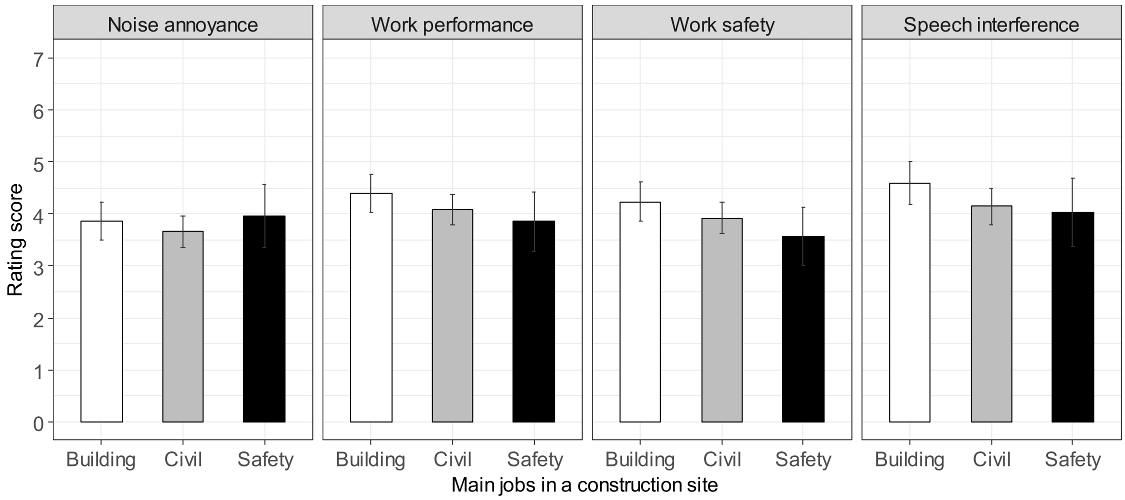

Fig. 4. Mean rating scores of self-reported adverse impacts of noise on noise annoyance, work performance, work safety, and speech interference on construction sites according to primary jobs (building construction, civil construction, and safety management). Error bars indicate 95% confidence intervals.

Table 4
Spearman's rank correlation coefficients among adverse impacts of noises with three main jobs (Building construction: n = 144, Civil construction: n = 234, and Safety management: n = 67).

	Main job	Work performance	Work safety	Speech interference
Noise annoyance	Building	0.27**	0.32**	0.24**
	Civil	0.61**	0.64**	0.60**
	Safety	0.70**	0.68**	0.66**
Work performance	Building		0.64**	0.64**
	Civil		0.80**	0.69**
	Safety		0.73**	0.76**
Work safety	Building			0.68**
	Civil			0.81**
	Safety			0.88**

$^{**}p < 0.01$.

$p = 0.76$), work performance ($F_{3,\ 451} = 1.31$, $p = 0.27$), work safety ($F_{3,\ 451} = 0.36$, $p = 0.78$), and speech interference ($F_{3,\ 451} = 0.16$, $p = 0.93$). Furthermore, as presented in Table 5, no trends of correlations between the four adverse impacts were observed across the years of working. Comparisons of the correlation confidents using Fisher's z transformation showed that there were no significant differences overall in the correlation coefficients among years of working. This indicates that the number of years of working at a construction

Table 5
Spearman's rank correlation coefficients among adverse impacts of noises with years of working (< 5 y: n = 120, 5–10 y: n = 180, 10–15 y: n = 91. and 15 y < : n = 70).

	Years of working	Work performance	Work safety	Speech interference
Noise annoyance	5. >	0.55**	0.61**	0.54**
	5–10.	0.51**	0.52**	0.51**
	10–15.	0.53**	0.47**	0.48**
	15. <	0.45**	0.48**	0.38**
Work performance	5. >		0.78**	0.71**
	5–10.		0.69**	0.73**
	10–15.		0.77**	0.68**
	15. <		0.76**	0.56**
Work safety	5. >			0.78**
	5–10.			0.80**
	10–15.			0.80**
	15. <			0.72**

$^{**}p < 0.01$.

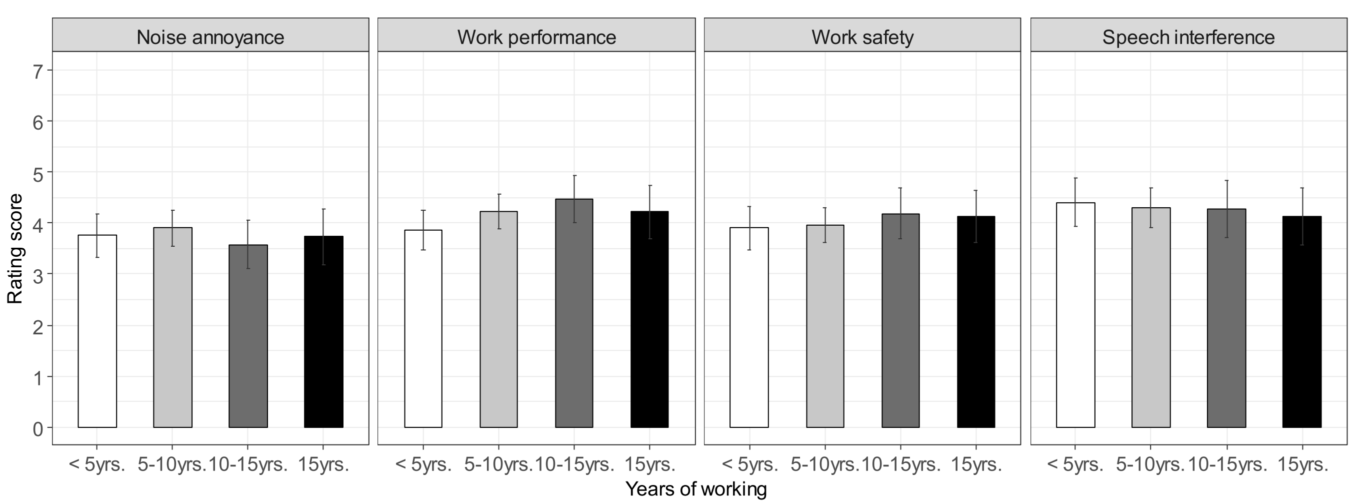

Fig. 5. Mean rating scores of self-reported adverse impacts of noise on noise annoyance, work performance, work safety, and speech interference on construction sites according to years of working in a construction company. Error bars indicate 95% confidence intervals.

Table 6
Regression models for four adverse impacts of noise with dummy variables (noise sensitivity, type of job, and years of working). D1–D3 indicates dummy variables; noise sensitivity and type of job, which have three levels, produced two dummy variables (D1 and D2), while years of working, which has four levels, created three dummy variables (D1–D3). "β" indicates standardized regression coefficients. Caret "^" indicates baseline level.

Dependant factors	Independent factors	β	t	p	R^2
Noise annoyance	Fit of model			< 0.001	0.06
	Noise sensitivity	0.23	4.98	< 0.001	
	Type of job: Building^				
	Type of job D1: Civil	−0.05	−0.84	0.40	
	Type of job D2: Safety	0.01	0.21	0.83	
	Years of working: < 5^				
	Years of working D1:5–10	0.05	0.86	0.39	
	Years of working D2:10–15	−0.01	−0.25	0.80	
	Years of working D3: 15 <	0.03	0.54	0.59	
Work performance	Fit of model			< 0.001	0.16
	Noise sensitivity	0.38	8.59	< 0.001	
	Type of job: Building^				
	Type of job D1: Civil	−0.08	−1.57	0.12	
	Type of job D2: Safety	−0.14	−1.92	0.06	
	Years of working: < 5^				
	Years of working D1:5–10	0.10	1.92	0.06	
	Years of working D2:10–15	0.09	1.70	0.09	
	Years of working D3: 15 <	0.07	1.37	0.17	
Work safety	Fit of model			< 0.001	0.15
	Noise sensitivity	0.37	8.37	< 0.001	
	Type of job: Building^				
	Type of job D1: Civil	−0.08	−1.54	0.12	
	Type of job D2: Safety	−0.07	−1.42	0.16	
	Years of working: < 5^				
	Years of working D1:5–10	0.04	0.77	0.44	
	Years of working D2:10–15	0.08	1.58	0.12	
	Years of working D3: 15 <	0.05	1.03	0.30	
Speech interference	Fit of model			< 0.001	0.14
	Noise sensitivity	0.36	8.00	< 0.001	
	Type of job: Building^				
	Type of job D1: Civil	−0.09	−1.65	0.10	
	Type of job D2: Safety	−0.09	−1.79	0.07	
	Years of working: < 5^				
	Years of working D1:5–10	0.01	0.18	0.86	
	Years of working D2:10–15	0.01	0.26	0.79	
	Years of working D3: 15 <	0.00	−0.04	0.97	

company is not a critical factor influencing the assessment of adverse impacts of construction noise for construction managers.

3.2.3. Estimation of adverse impact of noise

Multivariate linear regression analyses were performed with all independent variables (noise sensitivity, type of job, and years of working) to explain the adverse impacts of noise (noise annoyance, work performance, work safety, and speech interference). The self-reported noise sensitivity rating score was used as an input variable. Dummy variables with possible values of "0" and "1" were used for the type of job and years of working. The type of job was described by two dummy variables (D1 and D2) for each adverse effect of noise. Three dummy variables were used for years of working for each adverse effect of noise (D1–D3).

Table 6 summarizes the results of the regression analyses. All regression models indicated statistically significant results for noise annoyance ($F_{6,\ 432} = 4.52$, $p < 0.001$), work performance ($F_{6,\ 432} = 13.78$, $p < 0.001$), work safety ($F_{6,\ 432} = 12.73$, $p < 0.001$), and speech interference ($F_{6,\ 432} = 11.32$, $p < 0.001$). Similar to the results of the aforementioned ANOVAs, only the self-reported noise sensitivity had significant positive influences on the adverse effects of noise ($p < 0.001$), whereas the effects of job type and years of working were not significant. The regression models clearly demonstrated that the subjective adverse impacts of noise increased as the individual noise sensitivity increased. Regarding the goodness-of-fit for the regression models, the regression model for noise annoyance had a lower R^2 value (0.06) than R^2 values for work performance (0.16), work safety (0.15), and speech interference (0.14). This implies that the noise sensitivity score might be a better predictor for adverse impacts on work performance, work safety, and speech interference than those on noise annoyance.

4. Discussion

4.1. Construction tasks-based noise control on construction sites

The acoustic characteristics of construction noises vary with both time and tasks throughout the construction process [6]. In this context, these survey results provide a subjective evaluation of construction managers on the degree of adverse impacts of noise across the construction stages. This information can be useful to identify tasks generating high noise annoyance and to effectively control the overall risk of adverse impact of noise at sites with respect to construction stages and machines.

According to the survey results, approximately 93.1% of the participants choose the early stages of construction (i.e., demolition (60.7%), foundation (23.6%), and earthwork (8.7%)) to be the most annoying. In other words, concreting and finishing work generate relatively less annoying noise than the early stages of construction. These results are supported by the findings of previous studies. Neitzel et al. [3] reported that not only mean noise exposure levels but also mean noise exposure time in site preparation and structural work stages were greater than those in the finishing work stage. Ballesteros et al. [1] also showed that the mean noise level measured in the excavation stage was approximately 73.5 dBA, which was higher than those in other stages such as framework, brickwork, and roof work.

The survey results also identified specific construction machines as the primary sources of annoying noise across the different stages of construction, as each stage consists of different activities and tasks and requires different types of machines. For instance, a breaker machine, a pile driver, and a concrete pump car were identified as the primary construction equipment at demolition, foundation, and concreting stages, respectively. In addition, since the construction machines exhibit various acoustic characteristics with regard to power and temporal aspects [7,10], not only noise levels but also temporal characteristics of a machine may affect the perception of an annoying construction machine at each stage. In the demolition stage, the participants identified three main annoying construction noise sources; breaker, demolition machine, and gang-form demolition, whose measured noise levels were 88.7, 65.9, and 105.0 dBA, respectively. Although breaker noise is lower than the noise level of gang-form demolition, breaker was selected as the most annoying construction machine. This result can be explained by the acoustic characteristics of breaker noise and gang-form demolition. The temporal structure of breaker noise can be characterized as quasi-steady impulse noise consisting of continuous burst sounds with a duration of less than 1 s. Meanwhile, noise from gang-form demolition is intermittent noise. A pile driver that emits higher noise level at 89.2 dBA with a high temporal variation of sounds [7] was perceived as more annoying compared to the other identified construction machines (pile extractor, earth auger, etc.) in the foundation stage. These findings correspond well with those of previous studies, according to which rapid impulse noise is more annoying than stationary or intermittent noise [7,52,53]. These findings demonstrate the importance of establishing relevant noise control and mitigation strategies with more attention to the acoustic characteristics of the primary machinery used in the various construction stages [1].

4.2. Personal and situational factors-based noise control on construction sites

As a personal factor, individual sensitivity to noise was found to be a critical factor significantly affecting the self-reported adverse impacts of noise at construction sites, which is in agreement with the findings of previous studies [16,27,29,54]. In addition, interestingly enough, significantly different correlation coefficients among the adverse items of noise were observed regarding the types of jobs at construction sites. This indicates that the interrelationships between the adverse effects of noise could differ depending on the primary roles and working areas for specific types of construction jobs. This supports the findings of previous studies [30,55,56] in that the influence of occupational noise exposure on determining subjective responses to noise is contingent upon the types of tasks in the workplace.

Interrelationships between the adverse effects of noise at construction sites may reflect a variety of environmental and job characteristics of construction managers. For building construction managers, perceived annoyance caused by construction noises is less related to other adverse impacts on work performance, safety, and speech interference, whereas more significant correlations were found between the adverse impacts of noise with regard to the four items for the civil construction and safety management groups.

The primary tasks for construction managers in the building construction group are typically performed indoors after the building structure (e.g., building frames and floors) is completed, while tasks for the civil construction and safety management groups are conducted outdoors at construction sites. Therefore, noise annoyance for the building construction group is less related to work performance, safety, and speech interference than for the civil construction and safety management groups.

For civil construction managers, the correlation between work safety and work performance was significantly stronger than that for building construction managers. One possible explanation for this is that civil construction managers typically work in open construction sites where construction machines such as breakers, pile drivers, and excavators operate and generate high noise levels, thereby resulting in greater correlation between the impacts of noise on work performance and work safety than for the other groups.

The primary role of safety managers is to implement risk assessment processes to reduce the likelihood and severity of accidents at construction sites. For safety managers, communication with construction workers is one of the critical factors that enhance safety measures and a safety culture at construction sites [57]. In this sense, safety managers can perceive that communication interference from noise could adversely contribute to accidents at construction sites, resulting in high correlations between speech interference and work safety.

The findings in this study also demonstrate that specific noise control measures should be established by taking job characteristics (e.g., main tasks and working environment) into account. For instance, although typically construction workers rely on hearing protection devices (HPDs) as a means of reducing noise exposure without considering the roles of jobs in construction sites, safety managers might be reluctant to use HPDs in construction because of concerns about the ability to communicate and issue warnings. The results of this survey prove that they are sensitive to noise in terms of work safety and speech interference. In this case, special HPDs that include communication headsets could be used for workers who depend primarily on communication on construction sites [2,34,58].

4.3. Limitations and future work

This study has several inherent limitations. There are two approaches to measure individual noise sensitivity: single-item question and multiple-item scales. Weinstein's Noise Sensitivity (WNS) scale [59] or Griefahn's Noise-Sensitivity Questionnaire (NoiSeQ) [60] are multiple-item scales that measure noise sensitivity. Even though many researchers have used a single item to evaluate individual noise sensitivity [38–42], some reported that individual noise sensitivity measured by multiple-item scales exhibited more reliable results than the single-item scale [27,61]. Therefore, it is necessary to apply multiple questions to assess workers' noise sensitivities in the future to enhance the reliability of the results.

The job characteristics can also be defined by multiple questions on various factors such as skill variety, autonomy, task identity, and feedback from the job itself [62]. However, the multiple questionnaire items to characterize the main jobs at construction sites were not included in this study. Therefore, future research is necessary to identify specific job characteristics of construction managers using multiple questions, which might affect the adverse impact of noise. In addition, it should be noted that this study is based on survey responses from a single construction company. Even though the company was large enough and there were enough participants, in the future, the survey should be expanded to other construction companies to obtain more generalized conclusions because different construction companies might have different management policies and cultures. Additionally, note that Fisher's z-transformation to test the differences between the groups in terms of personal and situational factors is only applicable to correlation coefficients in some cases. This is limited to provide a generalized model to explain the adverse impacts of noise with independent variables. Last, this study is based on a survey that does not provide physical construction noise data such as the measured noise levels of construction stages and machinery and the operating times of tasks [6]. In the future, construction noise monitoring should be conducted to collect actual noise level data throughout the entire construction process.

5. Conclusion

The subjective adverse effects of construction noise were investigated for construction managers through a survey, and it was found that annoyance of noise differs across different construction stages and machines. Of the construction stages, the demolition and foundation stages were found to be more annoying than the other construction stages due to the acoustic characteristics of machinery used in these stages. The machines used in these stages produce higher noise emission levels with high temporal variability than those of other construction machines used in the other stages. The noises generated from the breaker (quasi-steady impulsive noise) and pile driver (discrete impulse noise) were rated as the most annoying construction machines in the demolition and foundation stages, respectively.

Regarding the personal and situational factors of construction managers, noise sensitivity of construction managers significantly affected the assessment of adverse impacts of noise on annoyance, work performance, work safety, and speech interference. Meanwhile, the effect of years of working on the assessment of the self-rated adverse impacts of construction noise was not significant. The effect of job type was also not statistically significant on the self-rated adverse impacts of construction noise. However, significantly different interrelationships among the adverse impacts of noise were observed in case of the types of construction jobs. The findings of this study will provide comprehensive knowledge for both occupational health specialists and construction workers to ensure better noise management planning for decreasing exposure to high-noise in construction.

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