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Original Article

Radiation risk perception and its associated factors among residents living near nuclear power plants: A nationwide survey in Korea

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ABSTRACT

There has been increased interest in researching risk perception of radiation to implement successful risk communication, particularly given the recent worldwide nuclear policy movement regarding nuclear energy. This study aimed to investigate characteristics of risk perception among residents living near normally operating nuclear power plants in South Korea by identifying factors associated with risk perception. A survey was conducted with face-to-face interviews for 1200 residents aged 20–84 years by gender- and age-stratified random sampling. Risk perception was associated with trust perception in nuclear safety, but was not highly correlated with benefit perception for utilizing nuclear power. Relatively high risk perception was observed in women, older age groups, and residents not having experience of nuclear-related education or work. This association remained after adjusting for other factors including benefit perception, trust perception, and psychological distress. In addition to these individual characteristics, risk perception was also associated with a residential district's own unique context, indicating that a strategy of risk communication should be developed differently for residents facing nuclear-related circumstances. Given that risk perception can be changed, depending on social values such as safety culture and economic setting, further studies are required to understand the changing characteristics of radiation risk perception.

1. Introduction

Risk communication related to radiation often is challenging, particularly considering that health consequences from low-dose radiation (e.g., <100 mSv) remain unclear. This is mainly because of different perceived levels of radiation risk among and even within groups, such as the general public, experts, and government, due to knowledge gaps of radiation-induced health risks and/or conflicting interests among stakeholders [1]. As such, the International Atomic Energy Agency emphasized that it is important to consider the different characteristics of each target population for risk communication when information is provided to different receivers [2].

Recent studies have explored characteristics of radiation risk perception based on the exposure and the context of the exposed population. For example, among nuclear-related researchers, risk perception was related to working duration or level of knowledge about low-level radiation [3]. Similarly, those who work on nuclear emergencies showed a low-risk perception when they had either research experience or a higher level of knowledge about nuclear safety [4]. On the other hand, if a living area has the possibility of radiation exposure, risk perception can be related to other factors. In 2011, some roads in Seoul, Korea, were revealed to be contaminated with Cesium-137; a study of 8875 local residents revealed that their risk perception was associated with demographic factors, including education level, age, and gender [5].

However, information as to which factors are associated with radiation risk perception, particularly for residents living near nuclear power plants, who can be considered the priority population for risk communication in case of a nuclear emergency or a change

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of nuclear energy policy (e.g., nuclear power phase-out, nuclear power plant construction). In addition, given that radiation risk perception may interact with a diverse array of subjective perceptions [6], it is necessary to understand the characteristics of risk perception taking into consideration other subjective perceptions, possibly influenced by socio-economic benefits for local communities supplied by nuclear power plant operators or government, trust in nuclear safety, and individuals' psychological status (e.g., depression).

Since the Fukushima accident, awareness of radiation effects on health has increased alongside concerns about nuclear power plants in South Korea. Accordingly, there are social conflicts concerning nuclear power plants such as whether to stop operating nuclear power plants, build new nuclear power plants, or extend the operation of old reactors. Thus, this study sought to understand radiation risk perception among residents living near nuclear power plants in South Korea by identifying related factors with consideration of diverse perceptions, including benefit perception for utilizing nuclear power, trust in nuclear safety, and psychological distress.

2. Material and methods

2.1. Study design and participants

The survey was conducted on residents who lived in administrative districts ('Eup' or 'Myeon' unit) included in the precautionary action zone (PAZ) within a 3–5 km radius from the following four nuclear power plant sites in South Korea: Kori, Hanbit, Wolsong and Hanul. Stratified random sampling by gender and age was used to survey 1200 participants aged 20–84 years (300 residents in each nuclear power plant site); the survey was designed with a sampling error of 3% at a 95% confidence interval. The survey was conducted through face-to-face interviews on August 1, 2016, and continued for twenty days until 1200 eligible people (300 residents in each nuclear power plant site) completed the survey per relevant guidelines as follows. In brief, thirty-two professional interviewers (eight interviewers in each nuclear power plant site), who were trained and educated about the questionnaires and the standardized survey process, visited houses randomly selected from the national administrative household address database. Before starting the survey, respondents were fully explained about the survey and had to explicitly express their consent with their participation in the study. Participation was voluntary, and thus if respondents stopped responding any time before or during the survey, interviewers visited the next houses in the order of the pre-selected household address to be surveyed. This study was approved by the Institutional Review Board at the Korea Institute of Radiological & Medical Sciences (K- 1603–002 - 034).

2.2. Questionnaires

The questionnaire was developed by radiation and health professionals by referring to the Korea Community Health Survey Data [7]. It included the following four domains: risk perception of radiation (hereafter, risk perception), benefit perception for utilizing nuclear power (hereafter, benefit perception), trust perception in nuclear safety and information (hereafter, trust perception), and psychological distress. Each domain consisted of 2–6 question items (Table 1) with Likert scales that ranged from 0 to 4 (from strongly disagree to strongly agree); the internal consistency of each domain was validated (Cronbach's alpha >0.6). These four factors were assessed with the average value of items in each domain.

The questionnaire included comprehensive demographic information, including the participant's gender, age, residence duration, occupation, marital status, supplemental security income program, monthly household income, and whether they were living with family. Additionally, we collected their personal experience related to nuclear matters, including their education about radiation risks, main sources of nuclear information, and nuclear-related work experience. The questionnaire was reviewed by a committee of civilian experts to ensure participants' understanding of the survey questions.

2.3. Statistical methods

To compare the mean score of risk perception by each category in the variables of demographic information or personal experience related to nuclear matters, we used a *t*-test for dichotomous variables and an analysis of variance (ANOVA) for variables with more than two levels. In addition, nonparametric tests, such as the Wilcoxon rank-sum test and Kruskal-Wallis test, were also employed due to the nature of some variables with ordinal scales. Multiple linear regression was conducted to identify factors associated with radiation risk perception with a backward model selection. Additionally, nuclear-related perceptions (i.e., benefit perception, trust perception) and psychological distress were adjusted in the final model with adding adjustment term ($Y = b_0 + b_1X_1 + b_2X_2 + \ldots + b_nX_n + b_{benefit}X_{benefit} + b_{trust}X_{trust} + b_{distress}X_{distress}$, where Y is risk perception and $X_{1\ldots n}$ are factors associated with radiation risk perception previously selected from the backward model selection). The data were analyzed using SAS version 9.4 (SAS Institute Inc. in Cary, NC).

3. Results

3.1. Characteristics of study population and risk perception

Demographics and personal experience related to nuclear matters among the 1200 participants were summarized for each nuclear power plant site (Table S1). More than half of the participants have lived in these regions for 20 years or more and have not received education about radiation risk. Comparisons of risk perception by demographics and experience related to nuclear matters are presented in Table 2. Overall, it was found that risk perception was greater than the middle value (neutral) of the Likert scale. Risk perception among the four nuclear power plant sites, Kori, Hanul, and Wolsong, had higher risk perception than Hanbit, and the highest risk perception was observed in the Wolsong area. Risk perception differed in most variables for participants' characteristics, except for the main source of nuclear information and supplementary security income program. Those results were consistent with the results from nonparametric tests using the Wilcoxon rank-sum test and Kruskal-Wallis test depending on the number of groups to be compared.

Evaluation of correlations among risk perception, benefit perception, trust perception, and psychological distress are presented in Table 3. The correlation between risk perception and trust perceptions was negative; its magnitude was relatively higher than the correlations with the other domains with weak associations (absolute values of Spearman's correlation coefficients <0.1), although their p-values were <0.05.

3.2. Factors associated with risk perception

To identify factors associated with risk perception, a multiple regression analysis was conducted, indicating that region (nuclear power plant sites), age, gender, educational experience about

Table 1
Questionnaire items per types of perception (5-point Likert scale).

Perception	Question items (Description)
Risk	1. The hazards of nuclear power cannot be controlled by individual efforts.
	2. The hazards of nuclear power are fatal to humans and harmful to nature.
	3. The hazards of nuclear power are extremely scary.
	4. The hazards of nuclear power will impact the next generation.
	5. The consequences of nuclear power's hazards are irreversible.
Benefit	1. Nuclear power will improve quality of life when it is applied to public health, medical care, food, and the environment.
	2. Nuclear power will contribute to the development of the national economy when it is applied to various fields of industry.
	3. The benefits of nuclear power will outweigh the losses from it.
Trust	1. The information provided by radiation specialists or medical professionals pertaining to radiation risk is reliable.
	2. Our government's countermeasure for radiation risk issues is reliable.
Psychological distress	1. How often did you feel irritable?
	2. How often did you feel hopeless?
	3. How often did you feel anxious or restless?
	4. How often did you feel depressed, and nothing could uplift your spirits?
	5. How often did you feel challenged by everything?
	6. How often did you feel worthless?

*Perceptions range from (1 = "Strongly disagree," 2 = "Disagree," 3 = "Neutral," 4 = "Agree," 5 = "Strongly agree").
Depression items range from (1 = "All days in a month," 2 = "Most days in a month," 3 = "Half days in a month," 4 = "Several days in a month," 5 = "None").

radiation risks, and nuclear-related work experience remained significant (Table 4).

Overall, those participants who lived in the regions of Kori, Wolsong, and Hanul had significantly higher risk perceptions than those who lived in Hanbit. Risk perception was higher among women and older age groups. Participants who had been educated about radiation risk or were currently working in nuclear-related workplaces had lower risk perceptions than those without such experiences. These associations remained after adjusting for benefit perception, trust perception, and psychological distress (Table 5).

4. Discussion

Our findings about the association between risk perception and socio-demographic characteristics are supported by studies conducted in other countries. After the Fukushima accident, high risk perception was revealed among women and the older adults in Japan [8,9]. Likewise, a Chinese study of people near nuclear power plants showed relatively high risk perception in women [10]. Furthermore, a study that reported gender differences in environmental risk perception explained that women are likely to be sensitive toward risky environments and experience increased stress and anxiety [11]. In addition, lower education levels were associated with high risk perception in previous studies [8,10]. Although the association between education levels and risk perception in this study was diluted in the multiple regression model, mainly due to adjustment of age which was related to education levels, we cannot rule out that education level is also likely to have meaningful influences by itself, considering the distinct increase trend of risk perception observed according to lower education levels (Table 2). Characteristics of socio-demographic factors associated with radiation risk perception were also similarly shown in the overall perception of other technological and industrial risks, including radiation or nuclear matters, although there were discrepancies in the individual perception among various types of risks [12]. Moreover, considering that those characteristics mostly retain over time, the socio-demographic background is fundamental information to understand discrepancies of perceived level of risk among the population, facilitating effective risk communication.

For the association between risk perception and educational experience about radiation risk, a study that found similar results provides a hint to understand their associations. After receiving education about advanced nuclear safety, experts expressed a lower risk perception than before receiving the education [13]. This may partially explain a lower risk perception among participants in this study who were currently working in nuclear-related workplaces, considering that radiation workers in South Korea should receive radiation safety education every year. Current workers may also have relatively low risk perceptions as they might have a high acceptance of a radiation-related job. However, workers concerned about radiation-related health risks are likely to leave their employment, indicating few differences in risk perception between former workers and those without nuclear-related work experience in this study.

As mentioned earlier, the regions of Kori, Wolsong, and Hanul had higher risk perceptions than Hanbit. This may be because each nuclear power plant site entails a unique context. For example, the Kori sites had the oldest nuclear power plants, and there were public calls for the shutdown of the oldest reactors [14]. Furthermore, heavy water reactors have been operating in the Wolsong site only, and concerns about tritium exposure among residents have continued [15]. These contentious issues may have influenced residents' risk perception in these regions.

Conversely, relatively low risk perception may bring about challenges of providing nuclear safety education and radiation risk communication. Indeed, the majority of participants (89%) in the Hanbit area, where risk perception was the lowest, did not receive education about radiation risk, and the rate of participants who did not have an interest or did not feel the necessity of education for the reasons of not receiving the education was 50%, the highest among the four nuclear sites, compared to 42% for Kori, 35% for Hanul, and 8% for Wolsong (Table S2).

This study had some limitations. First, each region had a different rejection rate (i.e., refusal before the survey or withdrawal during the survey) of 13–47% when recruiting survey participants of 300 residents for each region, which may have caused nonresponse bias (Table S3). Particularly, rejection rates in Kori and Hanul were 47% and 33%, respectively, higher than other areas with rejection rates of 13–19%. Thus, risk perception among participants in the areas of Kori and Hanul might be biased towards underestimation. However, considering that nonresponses due to voluntary sampling did not seem to necessarily bias the associations between survey items [16], they may not have highly influenced our findings to identify factors associated with risk perception. Nonetheless, we cannot rule out that nonresponse bias may moderate associations between risk perception and related factors. Moreover, other

Table 2
Risk perception by demographic characteristics and personal experience of nuclear matters.

Variable	Total N (%)	Risk perception		p-value[b]
		Mean ± SD[a]	Median (Q1-Q3)	
Demographic variables				
Region (nuclear power plant sites)				
Kori	300 (25.0)	4.15 ± 0.54	4.20 (3.80–4.60)	<.0001
Hanbit	300 (25.0)	3.75 ± 0.61	3.80 (3.40–4.20)	
Wolsong	300 (25.0)	4.55 ± 0.57	4.80 (4.20–5.00)	
Hanul	300 (25.0)	4.07 ± 0.70	4.20 (3.60–4.60)	
Gender				
Male	621 (51.8)	4.08 ± 0.70	4.00 (3.60–4.60)	0.0028
Female	579 (48.3)	4.19 ± 0.64	4.20 (3.80–4.80)	
Age				
20-29	170 (14.2)	3.94 ± 0.71	4.00 (3.40–4.40)	<.0001
30-49	389 (32.4)	4.06 ± 0.68	4.20 (3.60–4.60)	
50-59	267 (22.3)	4.24 ± 0.63	4.20 (3.80–4.80)	
≥60	374 (31.2)	4.21 ± 0.64	4.00 (3.80–4.80)	
Residence duration				
Under 5 years	94 (7.8)	4.03 ± 0.66	4.00 (1.80–5.00)	0.0113
5–9 years	78 (6.5)	4.11 ± 0.65	4.20 (2.40–5.00)	
10–19 years	137 (11.4)	3.99 ± 0.61	4.00 (2.20–5.00)	
20 years or more	891 (74.3)	4.17 ± 0.68	4.20 (1.00–5.00)	
Education level				
Elementary school	244 (20.3)	4.28 ± 0.63	4.40 (3.80–4.80)	<.0001
Middle school	165 (13.8)	4.21 ± 0.64	4.40 (3.80–4.60)	
High school	514 (42.8)	4.06 ± 0.67	4.20 (3.60–4.60)	
University or beyond	277 (23.1)	4.09 ± 0.70	4.00 (3.60–4.60)	
Occupations				
Agricultural, forestry, or fishery worker	216 (18.0)	4.06 ± 0.74	4.00 (3.60–4.80)	0.0199
Student	77 (6.4)	3.97 ± 0.71	4.00 (3.60–4.40)	
Housekeeper	193 (16.1)	4.11 ± 0.63	4.20 (3.80–4.60)	
Unemployed	160 (13.3)	4.23 ± 0.61	4.40 (3.80–4.80)	
Others	554 (46.2)	4.16 ± 0.66	4.20 (3.80–4.80)	
Marital status				
Married	801 (66.8)	4.15 ± 0.67	4.20 (3.60–4.80)	0.0143
Divorced or separated	27 (2.3)	4.21 ± 0.60	4.20 (3.80–4.60)	
Widowed	131 (10.9)	4.23 ± 0.62	4.40 (3.80–4.80)	
Single	241 (20.1)	4.02 ± 0.70	4.00 (3.60–4.60)	
Supplemental security income program				
Currently received	12 (1.0)	3.95 ± 0.71	4.00 (3.30–4.40)	0.3508
Ever received	6 (0.5)	3.83 ± 0.43	3.80 (3.40–4.20)	
Never received	1182 (98.5)	4.14 ± 0.67	4.20 (3.60–4.80)	
Monthly household income				
Less than 2 million won	377 (31.4)	4.20 ± 0.64	4.20 (3.80–4.80)	<.0001
2–3 million won	292 (24.3)	4.00 ± 0.63	4.00 (3.60–4.40)	
3–4 million won	302 (25.2)	4.06 ± 0.67	4.20 (3.60–4.60)	
More than 4 million won	229 (19.1)	4.28 ± 0.73	4.40 (3.80–5.00)	
Living with the family[c]				
None	748 (62.3)	4.12 ± 0.67	4.20 (3.60–4.60)	0.0378
Elementary school	183 (15.3)	4.09 ± 0.69	4.20 (3.60–4.60)	
Middle or high school	133 (11.1)	4.10 ± 0.70	4.20 (3.60–4.60)	
Adult	136 (11.3)	4.29 ± 0.61	4.40 (3.80–4.80)	
Personal experience related to nuclear matters				
Education about radiation risk				
Yes	340 (28.3)	4.05 ± 0.68	4.10 (3.60–4.60)	0.0111
No	860 (71.7)	4.16 ± 0.67	4.20 (3.80–4.80)	
Main source of nuclear information				
Mass media	825 (68.8)	4.15 ± 0.66	4.20 (3.80–4.80)	0.1911
Surrounding people	232 (19.3)	4.12 ± 0.70	4.00 (3.60–4.80)	
Nuclear-related reading materials	60 (5.0)	4.04 ± 0.69	4.00 (3.40–4.60)	
The internet	83 (6.9)	4.01 ± 0.66	4.00 (3.60–4.60)	
Nuclear-related work experience				
Current worker	33 (2.8)	3.63 ± 0.84	3.80 (3.20–4.20)	<.0001
Former worker	49 (4.1)	4.19 ± 0.76	4.20 (3.80–4.80)	
Never worked	1118 (93.2)	4.14 ± 0.66	4.20 (3.80–4.80)	

[a] SD: standard deviation.
[b] Inequality test for the comparison of means with *t*-test or ANOVA.
[c] The youngest person among a family living together.

nuclear-related perceptions (i.e., benefit and trust perceptions) and psychological distress were considered confounders that may attenuate a possible nonresponse bias in evaluating the association with risk perception.

Second, there might be other risk perception-related factors that were not included in this study. For instance, a previous study reported that knowledge levels on radiation effects were associated with risk perception [17], and this factor might be a more direct

Table 3
Correlations with 95% confidence intervals among risk perception, benefit perception, trust perception, and psychological distress.

Factors	Risk perception	Benefit perception	Trust perception
Risk perception	–		
Benefit perception	0.07 (0.01, 0.13)*	–	
Trust perception	−0.21 (−0.27, −0.16)**	0.17 (0.12, 0.23)**	–
Psychological distress	−0.06 (−0.12, −0.01)*	−0.18 (−0.23, −0.12)**	−0.17 (−0.22, −0.11)**

**p < 0.001, *p < 0.05.

Table 4
Factors associated with risk perception.

Variable	Coefficient	SE[a]	p-value[b]
Region (nuclear power plant sites)			
Kori	0.419	0.050	<.001
Wolsong	0.792	0.049	<.001
Hanul	0.384	0.051	<.001
Hanbit	Reference		
Gender			
Female	0.081	0.035	0.020
Male	Reference		
Education about radiation risk			
Yes	−0.114	0.042	0.007
No	Reference		
Age			
20-29	Reference		
30-49	0.113	0.055	0.038
50-59	0.279	0.059	<.001
≥60	0.214	0.056	<.001
Nuclear-related work experience			
Current worker	−0.419	0.108	<.001
Former worker	−0.104	0.088	0.238
Never worked	Reference		

[a] SE: standard error.
[b] Test for the significance of a regression coefficient.

Table 5
Factors associated with risk perception after adjusting for benefit perception, trust perception, and psychological distress.

Variable	Coefficient	SE[a]	p-value[b]
Other nuclear-related perceptions			
Benefit perception	0.082	0.029	0.005
Trust perception	−0.049	0.024	0.043
Psychological distress	−0.132	0.038	<.001
Region (nuclear power plant sites)			
Kori	0.413	0.051	<.001
Wolsong	0.755	0.053	<.001
Hanul	0.388	0.052	<.001
Hanbit	Reference		
Gender			
Female	0.082	0.035	0.018
Male	Reference		
Education about radiation risk			
Yes	−0.117	0.042	0.005
No	Reference		
Age			
20-29	Reference		
30-49	0.113	0.054	0.039
50-59	0.264	0.059	<.001
≥60	0.237	0.056	<.001
Nuclear-related work experience			
Currently worker	−0.408	0.108	<.001
Former worker	−0.107	0.087	0.222
Never worked	Reference		

[a] SE: standard error.
[b] Test for the significance of a regression coefficient.

measure associated with risk perception than the experience of education. In addition, risk perception is possibly influenced by education providers and their contents (e.g., anti-nuclear activists, nuclear operators). Therefore, further studies should consider additional informations to investigate change of risk perception according to not only knowledge levels on radiation but also characteristics of education sources.

Another limitation is that our findings were derived from outdated survey data. Although risk perception might have changed over the years depending on stakeholders' interests, such changes would be minimal, considering that there was no critical nuclear issue, such as a nuclear accident or a sudden change in nuclear policy since the period of the survey. However, because risk perception can also change according to social values, such as safety culture and economic setting, further studies are required to understand the changing characteristics of risk perception through a longitudinal study. Moreover, comparison with other populations (e.g., people who live far from the nuclear power plants or urban areas) will provide a better understanding of the nature of risk perception, considering that the nuclear power plant sites are located in rural areas where socio-demographic characteristics (e.g., older age structure and lower education levels) can be different from the national average [18].

5. Conclusion

This research sought to assess the characteristics of radiation risk perception among residents living near nuclear power plants. **A** relatively high risk perception was associated with low trust perception of nuclear safety but was not highly correlated with benefit perception for utilizing nuclear power. A risk perception gap was observed according to individual characteristics and each residential district's unique context, indicating that a strategy of risk communication should be developed differently for residents facing nuclear-related circumstances. Given the few studies about risk perception among residents living near normally operating nuclear power plants, our findings can provide a better understanding of risk perception among those residents to develop a strategy of radiation risk communication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.net.2021.10.017.

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