Cognitive Aversion of Mercury Scaled by Pairwise Comparison Method with Thurstone's Law of Comparative Judgement

Fumitake TAKAHASHI*

Department of Transdisciplinary Science and Engineering, Tokyo Institute of Technology
4259, Nagatsuta, Midori-ku, Yokohama, Kanagawa 226-8502, Japan
** E-mail: takahashi.f.af@m.titech.ac.jp*

Abstract

The Minamata Convention on Mercury, which entered into force on Aug. 2017, requires mercury to be recovered from society and its final disposal to be accomplished in environmentally safe ways. Because it is very difficult to obtain public acceptance of mercury landfill disposal, this study focuses on emotional perceptions of mercury. The author quantitatively evaluated aversions to mercury and other harmful matters such as radioactive waste or those perceived as hazardous using a pairwise comparison method with Thurstone's law of comparative judgement (sample size = 1030). The strongest aversion was found for radioactive waste, followed by mercury. Although gender and age usually affect risk perception to any hazard, this study found that gender and age had no significant impact on mercury aversion at the 5 percent significance level. When the participants had strong concerns about well-known hazards (radioactive waste, dioxins, infectious medical waste and cadmium), they had a stronger aversion to mercury than those who were concerned more with other matters like genetically modified foods or ultraviolet light. On the other hand, the participants who had moderate or weak concerns about well-known hazards had even greater mercury aversion than the group with strong concerns. No clear difference in mercury aversion was found regardless of different strengths of concerns regarding waste recycling. Cognitive aversion to mercury is associated with hazard perceptions and not affected by concerns regarding waste recycling.

Key words : cognitive aversion, mercury, pairwise comparison, quantitative evaluation

1. Introduction

Mercury is a liquid metal under natural conditions and has been used in many products like fluorescent lamps owing to its unique characteristics (UN Environment, 2019). Because mercury is highly toxic and its methylated species have bioaccumulative properties (Morel *et al*., 1998), international efforts have been made to reduce mercury applications. In this context, the Minamata Convention on Mercury was accepted on Oct. 2013 and effectuated on Aug. 2017 (UN Environment, 2019). It aims to protect human health and the environment from anthropogenic emissions and releases of mercury, including its compounds. Mercury applications are required to be reduced and/or substituted. Therefore, mercury, which is now used by society and industries, will need to be recovered for environmentally safe control. This means that the final disposal of recovered mercury in environmentally safe ways will be required in the near future. Mercury disposal in controlled landfill sites might be a feasible option (Lee & Lee, 2012). On the other hand, building public acceptance for construction of landfill sites for final mercury disposal is expected to be difficult. The major factors influencing public acceptance are risk perception, benefit perception and public attitude (Alhakami & Slovic, 1994; Barnett *et al*., 2007; Costa-Font *et al*., 2008; Purvis-Roberts *et al*., 2007; Schulte *et al*., 2004; Slovic *et al*., 1991). In addition, trust, knowledge and individual differences may also be greatly relevant (Gupta *et al*., 2012). Therefore, risk perceptions and attitudes toward mercury may be important considerations for forming acceptance for the construction of mercury landfill sites. According to Hirono's survey on the history of mercury applications, mercury toxicity has been known since the ancient Grecian era and many mercury poisonings have occurred, even before Minamata disease (Hirono, 2017). In risk perception research by Slovic, 81 hazards were analyzed focusing on 18 risk characteristics. These were categorized based on two major risks: dread risk and unknown risk (Slovic, 1987). Mercury was grouped in the high dread and high unknown risk categories along with cadmium and radioactive waste. On the other hand, risk perceptions can be affected by cultural and social background as well as context (Kinoshita, 2002; Kleinhesselink & Rosa, 1991). According to a study on mercury risk perceptions in Japan, methylmercury was perceived more strongly as a risk than other food-related hazards like high fat content, synthetic colorants and genetically modified materials (Niyama *et al*., 2011). Structural equation modeling proposes that knowledge and emotional appraisal of mercury hazards are associated with mercury risk perception as well as cognitive difficulty of avoiding mercury exposure. In contrast to mercury risk perception, cognitive attitudes to mercury are still uncertain, in particular in terms of long-term storage or landfill disposal. Therefore, as a first step, this study focused on emotional perceptions of mercury, in particular cognitive aversion. Cognitive aversion toward mercury was quantitatively measured using a pairwise comparison method. Personal characteristics like concerns about well-known hazards such as radioactive waste, dioxins and infectious medical waste and about waste recycling were also focused on in terms of their impact on cognitive aversion toward mercury.

2. Survey and Analysis Methods

2.1 Matters Targeted in Aversion Evaluation

To quantitatively scale cognitive aversion toward mercury, this study selected seven matters that also seemed subject to public aversion like mercury for comparison. These were radioactive waste, dioxins, infectious medical waste, cadmium, ultraviolet light, heavy noise, and genetically modified foods, listed in Table 1. Although genetically modified (GM) foods might not be appropriate as a hazard source, they were included owing to strong public concern about the safety of GM foods (Frewer *et al*., 2004; Bawa & Anilakumar, 2013).

2.2 Pairwise Comparison Method with Thurstone's Law of Comparative Judgement

This study quantitatively evaluated aversion to "*hazardous*" matters, listed in Table 1, using a pairwise comparison method with Thurstone's law of comparative judgement. A questionnaire survey was employed, with pairs of matters presented to the survey participants in random order. In this study, 45 pairs were shown to each participant for binary choice. The participants selected one matter to which they felt a stronger aversion. This method is based on a psychological model proposed by Thurstone (Thurstone, 1927). When two psychological stimuli are compared, they each invoke a "discriminal process" on a psychological continuum. The judgement between the two stimuli, which is a selection of the more abhorrent matter in this case, is driven by the rank produced by the discriminal process associated with each stimulus (Cheng *et al*., 2013). Because psychological processing usually fluctuates, the discriminal process is not fixed but subject to variation, called discriminal dispersion. In Thurstone's model, the probability distribution of the discriminal process is described by normal Gaussian distribution. The concept of this model is shown in Fig. 1. When Z_A and Z_B are the aversions that the survey participants perceive to matter A and matter B, respectively, the difference between the two aversions, ($Z_A - Z_B$) has the relationship of a cumulative normal distribution with a selection ratio of matter A (or matter B). When the aversion difference is larger, the selection ratio will increase or decrease correspondingly. When the two aversions are equal, no aversion difference is expected, resulting in a balanced selection ratio of each matter (0.5). This study used case V of the initial condition, in which the expected value (or mean) of the aversion difference was assumed to be zero and the variances of the discriminal dispersions of the two matter aversions were equal. The variance was set at 1.0, which is usual. As shown in Fig. 1, the selection ratio could be inversely transformed to the difference between two matter aversions. The aversion to matter A could be calculated from the average of all differences related to matter A because of the initial condition of zero mean. In this study, a larger score means greater aversion intensity.

2.3 Consistency of Respondence Data

Before the aversion was quantified, the consistency of participant respondence was checked. In the case of

Table 1 Matters tested for aversion evaluation.

Matter	Hazard	Source
Mercury	Neurotoxicity, like Minamata disease	Chang (1977)
Radioactive waste	Carcinogenicity	IARC (2001)
Dioxin	Carcinogenicity	IARC (1997)
Infectious medical waste	Pathogenicity	Windfeld and Brooks (2015)
Cadmium	Neurotoxicity, carcinogenicity	IARC (1993)
Ultraviolet light	Skin damage, carcinogenicity	IARC (1992)
PM2.5	Positive to cardiovascular and lung cancer mortality	Laden *et al*. (2006)
Noise	Adverse effects on cognitive performance	Stansfeld *et al*. (2005)
Gene-modified foods	Concerns about toxins, allergens or genetic hazards	Bawa and Anilakumar (2013)

three matters, say A, B and C for example, in all there are three possible pairs of two matters for pairwise comparison (A-B, A-C, and C-B). When one participant responds with aversion intensities in the order of A>B and B>C, the aversion to matter A is assumed to be greater than that to matter C (A>C) in terms of consistency. If the response is C>A, the aversion order will be circular (A>B>C>A), which is called a circular triad. To evaluate respondence consistency, Kendall proposed a coefficient of consistency (ξ), which is the ratio of the number of circular triads in one participant's respondence data to the theoretically maximum number of circular triads as described by Eq. 1 and 2 (Kendall, 1985), with "K" being the number of matters, and "d," the number of circular triads.

When K is odd

$$\xi = \frac{\frac{1}{24}(K^3-K)-d}{\frac{1}{24}(K^3-K)} = 1-\frac{24d}{K^3-K} \qquad \text{(Eq. 1)}$$

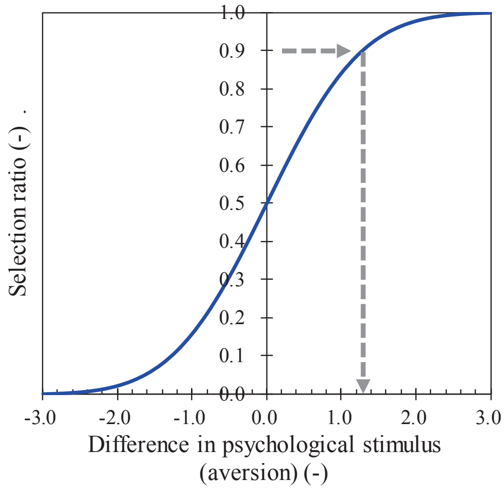

Fig. 1 Relationship between difference in aversion and selection ratio.

When K is even

$$\xi = \frac{\frac{1}{24}(K^3-4K)-d}{\frac{1}{24}(K^3-4K)} = 1-\frac{24d}{K^3-4K} \qquad \text{(Eq. 2)}$$

When the respondence is more consistent, ξ reaches 1.0. In contrast, worse consistency of the respondence causes ξ to approach 0. On the hypothesis that the participants give random selections in binary choices, the statistic χ^2, described by Eq. 3, follows χ^2 distribution with a degree of freedom described by Eq. 4 (Kendall, 1985). Therefore, the randomness of the respondence can be assessed by χ^2 test.

$$\chi^2 = \frac{8}{K-4}\left\{\frac{K(K-1)(K-2)}{24} - d + \frac{1}{2}\right\} + \text{df} \qquad \text{(Eq. 3)}$$

$$\text{df} = \frac{K(K-1)(K-2)}{(K-4)^2} \qquad \text{(Eq. 4)}$$

where df is degree of freedom, K is the number of the matters and d is the number of circular triads.

2.4 Web Questionnaire Surveys

Web questionnaire surveys were conducted in March 2018 by QuickMill®, Macromill Inc., Japan. The number of survey participants, sample size (N), was 1,030. The participants were randomly selected and anonymous to the author. On the other hand, each participant's respondence was traceable through a participant identification number. Therefore, cross-tabulation analysis was possible for detecting cognitive trends. The participants were pretreated to obtain equal gender ratios and an equal age distribution with 10-year age intervals (20s, 30s, 40s, 50s and 60s). Participant regionality might yield biased data. For example, public concerns about mercury and radioactive waste may be specifically large in Kumamoto and Fukushima, respectively. To prevent regionality-derived bias, participant pre-screening was also used to harmonize participant regionality with real regional population densities in Japan. The percentages of participants from Kumamoto and Fukushima were 1.4% and 0.7%, respectively. Attributes and demographic characteristics of the survey participants are shown in Fig. 2.

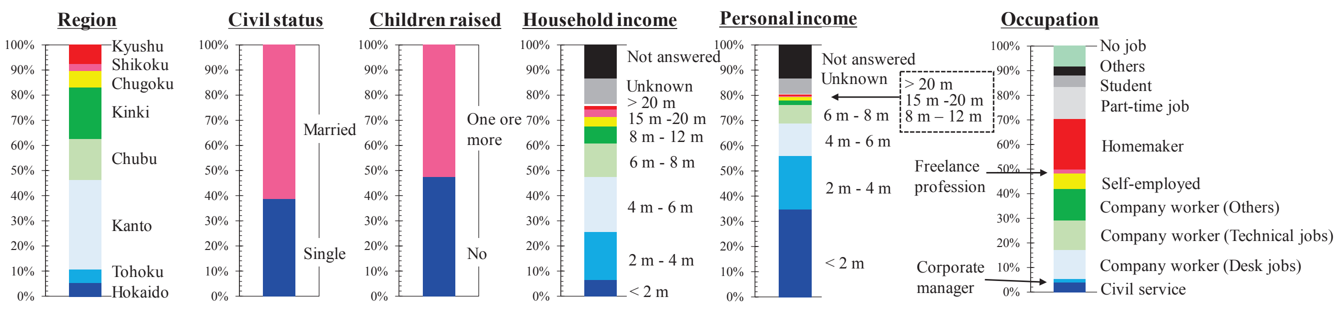

Fig. 2 Attributes and demographic properties of the survey respondents.

2.5 Aversion Score Adjustment for Comparisons and 95% Confidence Intervals

Not only the "*hazardous*" matters listed in Table 1 but also concerns about waste recycling were surveyed in the questionnaire. This consisted of six questions as follows: 1) Do you know the collection day of cans in your residence area? 2) Do you know the correct rules for can disposal? 3) Do you know the collection day for glass in your residence area? 4) Do you know the correct rules for glass disposal? 5) Do you wash cans before you dispose of them? 6) Do you separate PET bottles from other plastic wastes? Because the aversion scores evaluated by Thurstone's method are relative to each other, they can vary depending on the initial condition of variance (1.0 in this study). To fairly compare the aversion scores among different gender and age groups and different intensities of concerns about hazardous wastes and waste recycling, the range of aversions was adjusted to 2.0, with a maximum aversion score of 1.0 and minimum aversion score of −1.0. Owing to the methodology of Thurstone's approach, it is impossible to calculate 95% confidence intervals of aversion scores directly using a single survey dataset. Therefore, the 95% confidence interval of the selection ratio was first calculated and then the aversion score ranges were calculated. The 95% confidence intervals of the aversion scores were also adjusted correspondingly to be harmonized with the score range adjustment.

3. Results and Discussion

3.1 Respondence Data Quality

The consistency of the respondence data was assessed by the coefficient of consistency, and the cumulative distribution of the coefficient of consistency is shown in Fig. 3. Although there is no common standard to certify sufficient consistency, it is regarded as sufficient when the coefficient of consistency is more than 0.8 (Van Riel *et al*., 2016). More than 80% of the respondence data exceeds 0.8 (see Fig. 3a). In addition, more than 90% of the respondence data are regarded as non-random selection by the χ^2 test at the 5% significance level (see Fig. 3b). According to these results, it is concluded that this study successfully collected respondence data with sufficient quality.

3.2 Cognitive Aversions and Age/Gender Effects

Aversion scores of the matters tested are shown in Fig. 4. The error bar indicates the 95% confidence interval. The strongest aversion was found for radioactive waste. Strong concerns about radioactive waste may be the main contribution to this. Although the survey was limited to university students, public attention to everything "nuclear" has increased in Japan since the Fukushima Daiichi nuclear accident in 2011 (Gallardo *et al*., 2014). Mercury had the second strongest aversion followed by dioxins, infectious medical waste, PM2.5 and cadmium. Ultraviolet light and genetically modified

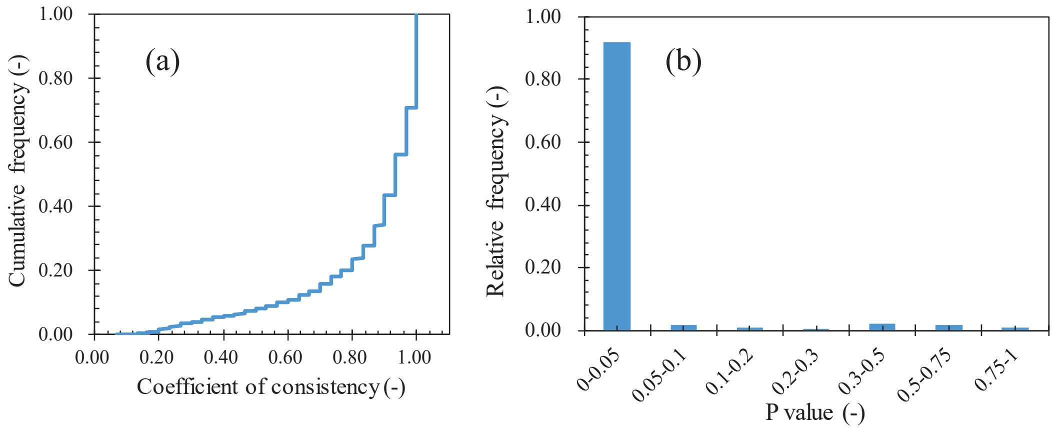

Fig. 3 Cumulative distribution of the coefficient of consistency (a) and P value frequency histogram (b).

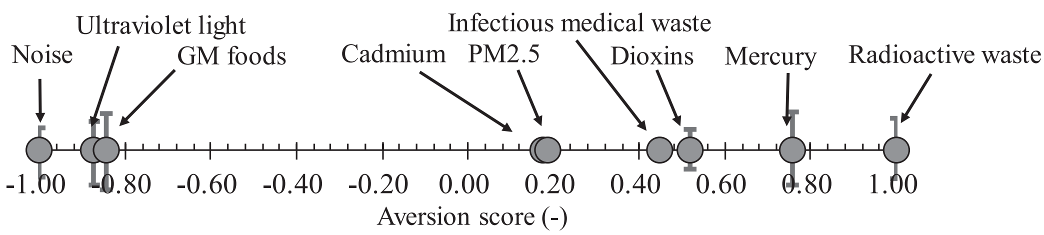

Fig. 4 Aversion scores of tested matters (after range adjustment).

foods provoked similar aversions which were greatly less than that to cadmium. Noise pollution elicited the weakest aversion among the matters tested. The 95% confidence intervals of the aversion scores do not overlap between radioactive waste and mercury, or between mercury and dioxins. This suggests that mercury elicits significantly larger and smaller aversions than dioxins and radioactive waste, respectively. On the other hand, dioxin aversion should be regarded as comparable with that to infectious medical waste owing to the large overlap of confidence intervals. Publicly shared lessons on Minamata disease may contribute to the strong aversion to mercury. For example, in-depth news and documentaries about Minamata disease, comprising straight news, school education, public welfare announcements and other sources, have been broadcasted periodically throughout the past 60 years (1956–2015), appearing more frequently in recent years (Kato *et al*., 2018). On the other hand, the strong mercury aversion might also result from environmental stigma (Colocousis, 2012). In fact, the stigmatization of contaminated or pseudo-contaminated matters has raised disgust (Rozin *et al*., 1985; Rozin *et al*., 1986; Kecinski *et al*., 2018) and this effect might be persistent (Kecinski *et al*., 2018). A long-term stigmatizing effect has been found in real estate asset valuation even after remediation (McCluskey & Rausser, 2003). As shown in Fig. 5, gender produced no significant differences in aversions. The paired t-test supports it at any significance level ($P = 1.000$) for aversion scores both with and without range adjustment. According to the two-way ANOVA test, not only gender but also age had no significant impact on mercury aversion at the 5% significance level ($P = 0.538$ for gender and $P = 0.618$ for age in range-adjusted data). It differs from risk perception to various hazards. Gender and age usually have significant or non-negligible impacts on risk perception (Siegrist *et al*., 2005). In terms of risk attitude, risk avoidance is higher among females than males and increases strongly with age (Dohmen *et al*., 2011). If mercury aversion is associated directly with risk avoidance, mercury aversion in females would be expected to be stronger than that in males. As expected, mercury aversion scores of the female group were 4% higher than that of male group when aversion scores without range adjustment were compared. On the other hand, the mercury aversion score of the female group was slightly lower than that of the male group for range-adjusted data. This inconsistency is caused by a limitation of Thurstone's model. As described above in Section 2.5, any scores scaled by Thurstone's method are relative to each other and can vary depending on the initial condition of the variance. To verify age and gender effects on mercury aversion, use of different approaches is recommended, like Scheffé's method, which consists of a main effect, combination effect, order effect and error terms based not on a psychophysical model but the multi-way ANOVA model (Scheffé, 1952; Inoue, 2012).

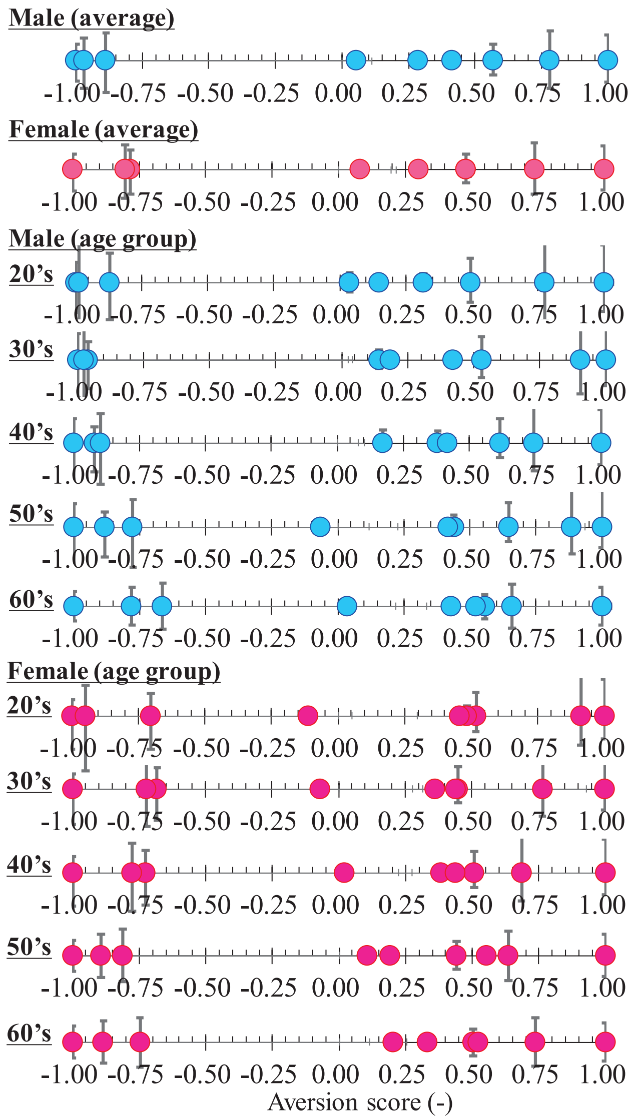

Fig. 5 Aversion scores for matters tested, by gender and age group.

3.3 Effects of Concerns about Other Hazards and Waste Recycling

People who are concerned strongly about hazardous matters like dioxins may have a stronger aversion to mercury. According to the respondence data, the participants were categorized into three groups based on the strength of their concerns regarding matters listed in Table 1, excluding mercury. In the case of dioxins, for example, the number of selections of dioxins in all binary choices was counted for each participant. When the number of dioxin selections was seven to eight, it was categorized as a strong concern about dioxins. If the number of selections was four to six they were categorized as moderate, and for zero to three, weak levels of concern. In the cases of GM foods, ultraviolet light and heavy noise, the categorization criteria were changed to 6–8 for strong concern, 3–5 for moderate

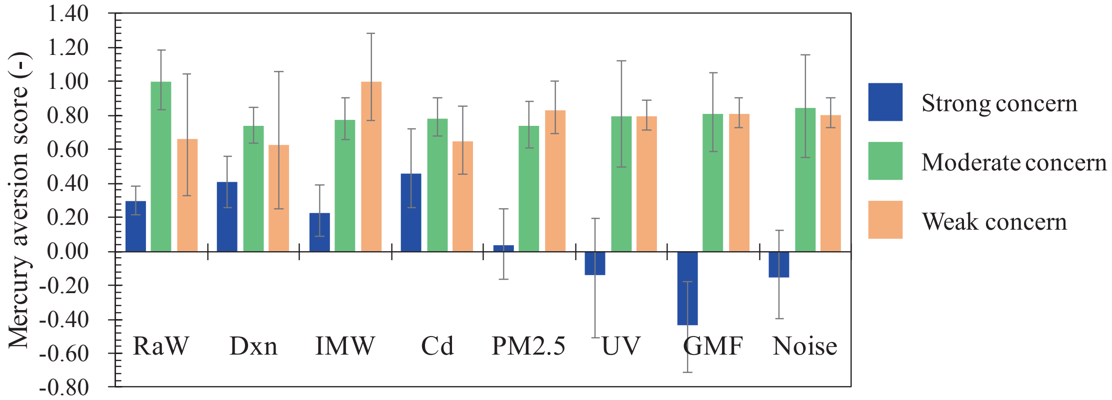

Fig. 6 Mercury aversion scores of groups with different concern intensity to tested matters (RaW: radioactive waste, Dxn: dioxins, IMW: infectious medical waste, Cd: cadmium, PM2.3: -, UV: ultraviolet light, GMF: genetically modified foods, Noise: heavy noise).

concern, and 0-2 for weak concern. The average mercury aversions of different concern strength groups are shown in Fig. 6. When the participants had strong concerns about well-known hazards, which were radioactive waste, dioxins, infectious medical waste and cadmium, they had a stronger aversion to mercury than those who were concerned more about other matters like GM foods, ultraviolet light and heavy noise. However, the two-way ANOVA test suggested that these differences were not significant at the 5% significance level (P = 0.762). On the other hand, the participants who had moderate or weak concerns about any of the tested hazards excluding mercury had stronger mercury aversion than the group with strong concerns (see Fig. 6). This is regarded as a significant difference according to a multiple comparison by the Tukey-Kramer method (P = 0.00005). In contrast to the initial expectations, cognitive aversion to mercury might not be associated directly with concerns about other hazards.

The participants were also categorized into three groups based on the strength of their concerns regarding waste recycling. They were categorized based on the number of positive answers (yes) to the six questions described above in Section 2.5. The categorization criteria was 5-6 for strong concern, 3-4 for moderate concern, and 0-2 for weak concern about waste recycling. Because Cronbach's alpha of the construct on waste recycling was 0.721, the internal consistency satisfied the acceptable level of the Nunnally criterion in terms of construct validity (Cronbach, 1951); Nunnally, 1978). Mercury aversions of groups with different levels of concern about waste recycling are shown in Fig. 7. No clear trend was found between mercury aversion and concern about waste recycling. Aiming for sustainability, an educational campaign for sustainable development has been emerging in Japan (Nomura & Abe, 2009). In fact, the environmental education campaign has been effective at raising awareness and concern about waste recycling and sustainable behaviors (Gallotti *et al*., 2012). In this social

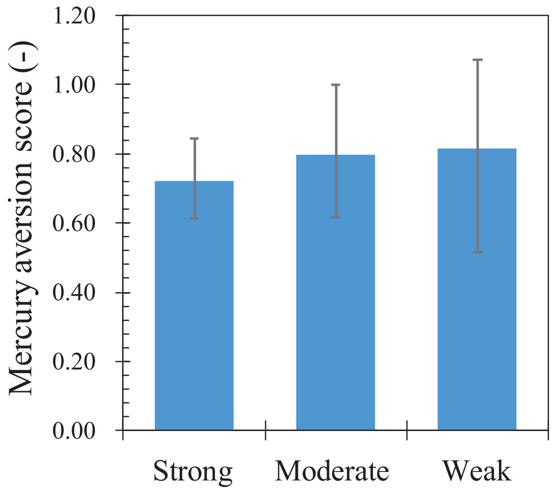

Fig. 7 Mercury aversions of groups with different levels of concern about waste recycling.

movement, the author expected that concerns encouraged regarding waste recycling by environmental education campaigns might collaterally mitigate the negative perception of mercury and thus help the mercury disposal problem be addressed more comprehensively. However, this study concluded that such a secondary effect on mercury aversion mitigation was unlikely.

3.4 Limitations

In this study, the associations of gender, age and concerns about the matters tested or waste recycling were investigated with regard to mercury aversion. It should be noted that the demographic properties tested are probably insufficient for an in-depth analysis to reach any generalized conclusions on mercury aversion. If mercury aversion is, more or less, associated with awareness of mercury toxicity, it should be considered that awareness and knowledge of methylmercury would be significantly linked to demographic characteristics like gender, race, education, income, fish preparation experience and risk perceptions, as reported by a survey in the US (Lando & Zhang, 2011). In addition, risk perception has strong links to gender, age, education, income and race (Savage, 1993). Not only demographic characteristics but also instinctive emotion processing might need to be considered. Negative emotions, in particular disgust, are elicited by risk perception of pathogen transmission (Curtis *et al*., 2004). Disgust efficiently functions to promote avoidance of contaminants (Davey & Bond, 2006) and/or hazardous substances (Rozin & Fallon, 1987). Disgust is often associated with the objective presence of health threats. It motivates avoidance, and appears to be predominantly a health-promoting discrete emotion (Consedine & Moskowitz, 2007). Although mercury aversion was quantified in this study, it is only a semblance of observations of emotions. Mercury aversion is produced through biological, personal and sociopsychological processing mechanisms.

4. Conclusions

This study quantified emotional perceptions of mercury. Cognitive aversions to mercury and other harmful matters like radioactive waste or those perceived as hazardous were quantitatively evaluated using a pairwise comparison method with Thurstone's law of comparative judgement (sample size = 1,030). The strongest aversion was found for radioactive waste, followed by mercury. Although gender and age usually affect risk perception of any hazard, this study found that gender and age had no significant impact on mercury aversion at the 5% significance level. To verify these results, use of different approaches is recommended like Scheffé's method, which was designed based on the multi-way ANOVA model. When the participants had strong concerns about well-known hazards (radioactive waste, dioxins, infectious medical waste and cadmium), they had stronger aversion to mercury than those who were concerned more about other matters like genetically modified foods and ultraviolet light. On the other hand, the participants who had moderate or weak concerns about well-known hazards had stronger mercury aversion than the group with strong concerns. No clear differences in mercury aversion were found regardless of different strength of concerns about waste recycling. Cognitive aversion to mercury is associated with hazard perception and not affected by concerns about waste recycling.

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Fumitake TAKAHASHI

Fumitake Takahashi is an associate professor in the Department of Transdisciplinary Science and Technology, School of Environment and Society, Tokyo Institute of Technology. He received his Ph. D. in Urban Engineering at the University of Tokyo. His current research fields include waste management, waste recycling, environmental risk assessment, socio-psychological analysis of waste recycling behaviors and recycling tools.

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