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Doctoral dissertation

Cognitive Preference of Trash Bin Design and The Effect of Bin Design on Waste Segregation and Collection Performances

by

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Abstract

Waste management has been concerned as one of social and environmental problems. Recycling bins are the most common and fundamental tools used to collect the waste. When the effective promotion, provision, and availability of appropriate recycling bins are achieved, it can significantly increase the participation levels in a recycling program and support its success. This study investigated perceptive preference toward recycling bin designs and design impact on waste segregation behaviors. Affective factors on design preferences and waste segregation behaviors are also included for comprehensive analysis of recycling bin designs and installation In our daily life, to encourage waste sorting using designed recycling bins, combination of modified design items is necessary and intensive usage of designed recycling bins for frequent perception opportunities recommended to support sufficient design preference. In addition, use the design associate with the waste items is also recommended. In the specific situation, to encourage the waste sorting using designed recycling bins. design items should be reconsidered according the surrounding environment. The setting location of recycling bin is important in the two social environments (daily life and firework events). Proper setting location based on the surrounding environmental can effective improve the human behavior (waste collection).

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Chapter 1 Introduction

1.1 Research Background

Waste management has been concerned as one of social and environmental problems (Rahardyan et al.2004; Morrissey and Browne, 2004; Gould et al., 2016). The world produces 2.01 billion tons of municipal solid waste every year, of which at least 33% are not managed in an environmentally safe way. Worldwide, the average waste generated per person per day is 0.74 kg, but the range varies from 0.11 to 4.54 kg. Although they account for only 16% of the world's population, high-income countries generate approximately 34% (683 million tons) of world waste. From the perspective of waste management, it is estimated that by 2050, global waste generation will increase to 3.40 billion tons, more than twice the population growth in the same period (The word bank, 2021). Waste collection and separation is a critical step in managing waste. In Japan, where one of most successful countries in waste treatment, almost all of Japanese people already know the importance of waste recycles. But the segregation efficiency of recyclable wastes is still too low in our daily life, especially in public places. For example, the recyclable papers and plastics are usually mixed into combustible wastes. In addition, we can always find other waste contamination in collected "pet bottle" wastes. In Japan, the main treatment of MSW is incineration. We can reasonably suggest that a lot of recyclable resources have been treated as combustible waste. There are urgent needs of waste management improvement, in particular, the process of waste collection and separation.

1.2 Recycling bins, human perception and recycling behavior

Recycling bins are the most common and fundamental tools used to collect the waste. When the effective promotion, provision, and availability of appropriate recycling bins are achieved, it can significantly increase the participation levels in a recycling program and support its success (Perry and Williams, 2007; Robinson and Read, 2005; Šauer et al., 2008; Wan et al., 2014; Willman, 2015). At the early stage of waste management, human perception and behaviors are important in terms of waste collection and segregation. In fact, human perception, beliefs, and attitudes can affect recycling behaviors (De Young, 1986; Huang et al., 2011; Nyamwange, 1996; Sia et al., 1985; Vining and Ebreo, 1990). Effective recycling mostly depends on appropriate infrastructure (Malakahmad et al., 2010; Yoreh and Horne, 2014). Previous studies show that there are strong connections around recycling bins, human perception and human behavior. Some visual impacts through recycling bins are useful to inform of a recycling scheme. Their distinctive appearance can serve as a visual signal of the users' ethical obligation to participate in recycling activities (Lakhan, 2016; McDonald and Ball, 1998; Smith et al.,1999). In this sense, the design of recycling bins and their impact on waste collection and separation performances have been concerned.

Table 1-1 shows a brief overview of the prior research for the recycling bin design. Andrews et al found commingled design of recycling bins performs high efficiency of recyclable waste separation (Andrews et al., 2013). Duffy and Verges reported that a lip/insert hole in the bin could encourage people to drop wastes correctly (Duffy and Verges, 2009). Keramitsoglou and Tsagarakis highlighted public preference of recycling bin designs focusing on color, shape, lid, insert slot, and signage with thorough reviews of previous researches (Keramitsoglou and Tsagarakis, 2018). Kalatzi et al found the distance and color have been significant factors for the selection of the recycling bin (Kalatzi et al, 2015). When recycling bins with inappropriate design were used with insufficient capacity, it resulted in poor collection efficiency (Pattnaik and Reddy, 2010). Location of recycling bins is a critical factor which affects waste collection performance of recycling bins (O'Connor et al., 2010). Aras and Anarat suggested the recycling bins should be put near the place with a higher amount of recyclable material (Aras and Anarat, 2016). Schloss et al also reported potential associations between the color and waste type (Schloss et al., 2018).

Table 1–1. Brief overview of prior studies on recycling bins design

Reference	Place (city,country)	Recycling bins	Desgn items	Method
Andrews et al., 2013	Chicago,usa	Original bins	Setting location,signage, bin type	Collection experiments
Duffy and verges, 2009	Usa	Designed bins	Lid	Collection experiments
Keramitsoglou and tsagarakis, 2018	Dilimoticho,greece	Designed bins	Lid,inesrt slot shape,color,signage	Questionnaires
Kalatzi et al, 2015	Greece	Designed bins	Color,distance	Questionnaires
Pattnaik and reddy, 2010	Pondicherry, india	Designed bins	Capacity	Collection experiments
O'connor et al., 2010	Usa	Original bins	Number, location	Collection experiments
Aras and anarat, 2016	Istanbul,turkey	Designed bins	Location	Collection experiments
Schloss et al., 2018	Usa	Designed bins	Color	Questionnaires

On the other hand, the systematic research of the recycling bin design and recycling bin researches based on on-site experiments (waste collections) are still limited. In particular, the design effect on waste collection and separation performances are still uncertain. For example, color is a significant factor for the selection of the recycling bin (Kalatzi et al., 2015). As introduced above, waste items individually affect design preferences toward recycling bins (Keramitsoglou and Tsagarakis, 2018). On the other hand, a critical question still remains whether design item preference is mainly controlled by associations to waste items or not. The preference toward product design can be affected by opportunity frequency of design perceptions or information exposure (Cox and Cox, 2002). For example, car design preference depends on exposure level (Landwehr et al., 2013).

In our study, the design items of recycling bins like color, insert slot, arrangement and signage are focused on. This study surveyed the popularity of design items for real recycling bins used in public sites and their perceptive preferences Potential association of usual experiences to perceive real designs of recycling bins in daily life with design preference were discussed. The effect of one design item on waste segregation was also verified by waste collection experiments. On the other hand, location of recycling bins is a critical factor which affects waste collection performance of recycling bins (O'Connor et al., 2010)., this study, human's psychological resistance (botheration) with the distance to the trash bin will be discussed. The location effect on waste separation will be investigated.

The recycling bins ae also used in the big events to manage the waste generated in a short time. In order to maximize the effectiveness of waste collection using recycling bins, appropriate design/installation (setting) of the recycling bins in public events are recommended. On the other hand, the Japanese people are already acquainted with waste separation and resource recycling rules, their behaviors can be changed under crowded conditions. The recycling bin installation in the public events might give different design impact on waste collection and separation. Therefore, recycling bins design and the design effect in the firework events were also considered in this research.

1.3 Methods

In this study, the data were collected from web-questionnaires, field investigation and on-site experiments. Thurston's law of comparative judgment was used to quantify the perceptive preference toward design and botheration. The t-test was used to check statistical significance of correlation coefficient. The statistical power (1-β) of the t-test was analyzed using G*Power 3.1 software (Frau et al., 2007; 2009). The Tukey-Kramer multiple comparison test was also used to check significance differences of usage rates of slot position using Excel® add-in software: Excel statistics® (Social Survey Research Information, Co., Ltd, Japan).

1.4 Research aims and objectives

The objectives of this study are to investigate perceptive preference toward recycling bin designs and design impact on waste segregation behaviors. Affective factors on design preferences and waste segregation behaviors are also included for comprehensive analysis of recycling bin designs and installation. Figure 1-1 shows the concept of this thesis. This thesis consists of seven chapters as follows. Chapter two focuses on the perceptive preference toward design items of recycling bins. Three design items, color and slot, and arrangements of recycling bins are discussed in this chapter. The preferred design of trash bin is considered can has positive effect on waste separation and collection.The purpose of chapter two is to measure the perceptive preference quantitatively. In chapter three, the impact of perception frequency of recycling bin designs on design preference was analyzed. To investigate it, this study surveyed the popularity of design items for real recycling bins used in public sites. In addition, the popularities of design items are compared with the perceptive preferences which are quantified in chapter two. The purpose of this chapter is to find out the potential association of usual experiences to perceive real designs of recycling bins in daily life with design preference. Chapter four focuses on the waste collection experiment conducted in in Suzukakeidai campus, Tokyo Insitute of Technology. The purpose of chapter four is to investigate the effect of recycling bin design and installation location on waste segregation. Chapter five focuses on cap removal from PET bottles and recycling contamination ratio in a recycling bins of PET bottles. Ten different recycling bins were designed for PET bottle in order to explore design preference toward PET bottle recycling bins and its effect on collection performance of PET bottles. Chapter six focuses on the recycling bins installation in firework events. The impact of the recycling bin designs and installation on waste collection and waste separation will be discussed. This chapter aims to find out appropriate design/installation of recycling bins firework events. Chapter seven summarizes the findings of this study, suggests a guideline for recycling bins design, and list some recommendations for the further study.

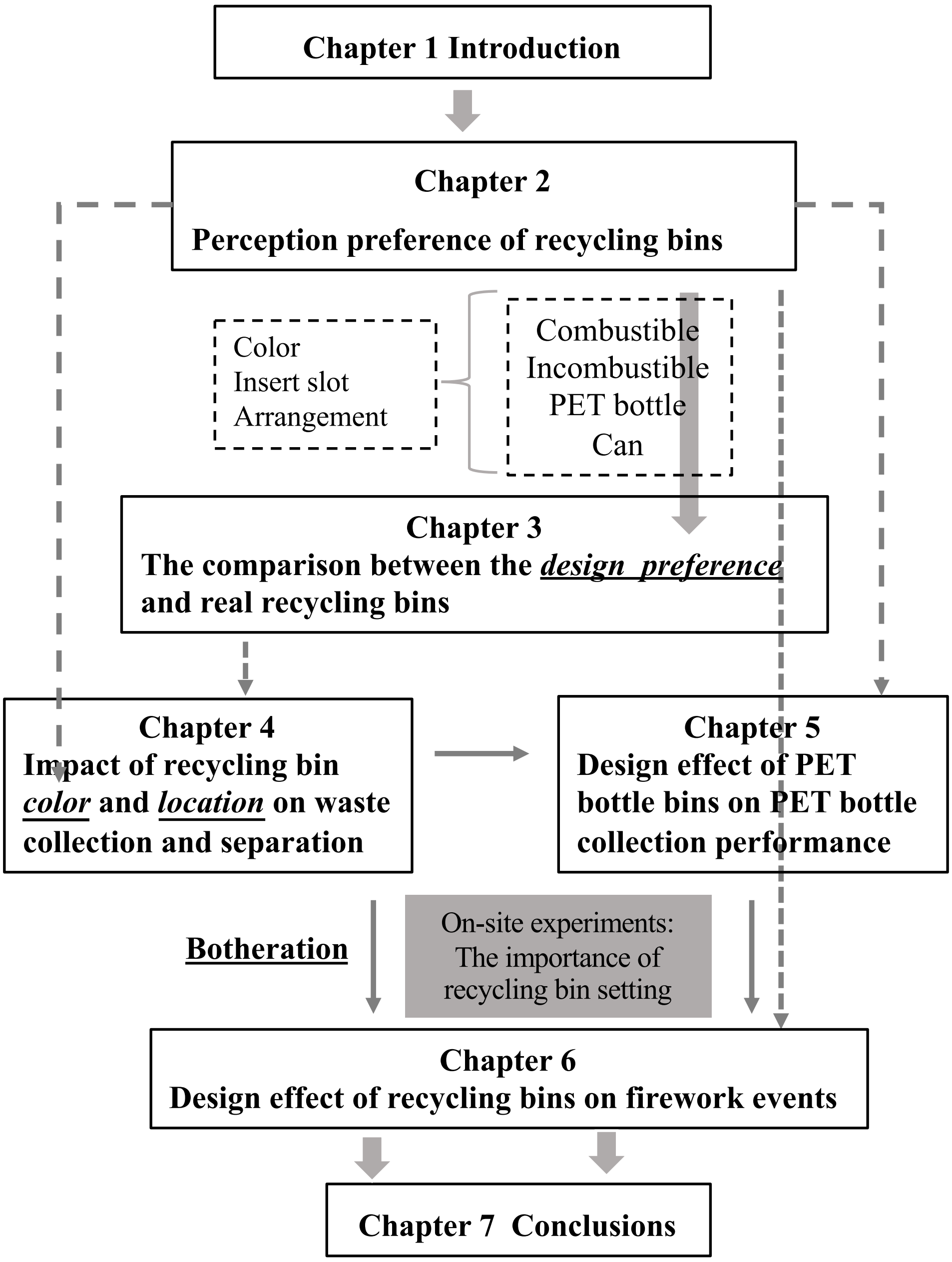


Figure 1–1 The concept of thesis

Chapter 2 Perception preference of recycling bins design

2.1 Introduction

This study focuses on three design items of recycling bins. They are color, insert slot, and bin arrangement. Recycling bins with different design items were analyzed by web-questionnaires. Perceptive preference toward design items of recycling bins are quantified by pairwise comparison method.

2.2 Methods

2.2.1 Designed recycling bins for web-questionnaires

2.2.1.1 Color

This study tested ten different colors to survey color preference toward recycling bins. The tested colors were three primary colors (blue, red, and yellow), their mixed colors (brown, green, orange, and purple), and monochrome colors (white, gray, and black) (see Figure 2-1a). The preference toward four waste types of recycling bins (combustible waste, incombustible waste, PET bottle, and can) were quantified by pairwise comparison method with Thurston's law of comparative judgment. In this survey, colors were shown as body color of recycling bins for easy color perception by the questionnaire respondents. This study also focused on colored area of recycling bin body. To investigate its impact on design preference, six combustible waste bins with different red-colored designs were also tested for preference quantification (see Figure 2-1b).

2.2.1.2 Insert slot

For preference quantification of insert slot shapes, this study tested seven slot shapes for combustible waste bins, incombustible waste bins, and can bins. On the other hand, six slot shapes were tested for PET bottle bins (see Figure 2-2a, Figure 2-2b, Figure 2-2c). For combustible and incombustible waste bins, tested slot shapes were single square, single circle, rectangle, two squares, trapezoid, ellipse, and stadium. For PET bottle bins, tested slot shapes were single square, single circle, rectangle, bottle-like shape, two circles, and ellipse. For can bins, single square, single circle, rectangle, bottle-like shape, two circles, ellipse, and stadium were tested. In the slot shape preference surveys, three different body colors (gray, blue, and red) were used for combustible waste bins, incombustible waste bins, and can bins. For PET bottle bins, four different body colors (gray, blue, red, and white) were tested to confirm an interactive effect on design preference between body color and slot shape. In addition, six recycling bins with different insert slot position (front, slope and top) were also designed to investigate the preference toward slot position (see Figure 2-3).

2.2.1.3 Arrangement

In this study, four recycling bins are used to investigate the preference degree of their arrangement, there are recycling bins for combustible waste, incombustible waste, PET bottle and can. In addition, 3 of the 4 recycling bins and 4 recycling bins arrangements were tested. Figure 2-4a and Figure 2-4b shows the arrangements in the case of three and four recycling bins. Therefore, in three recycling bins case, have 4*A (3,3) =24 arrangements. In 4 recycling bins case, have 4A (4,4) =24 arrangements.

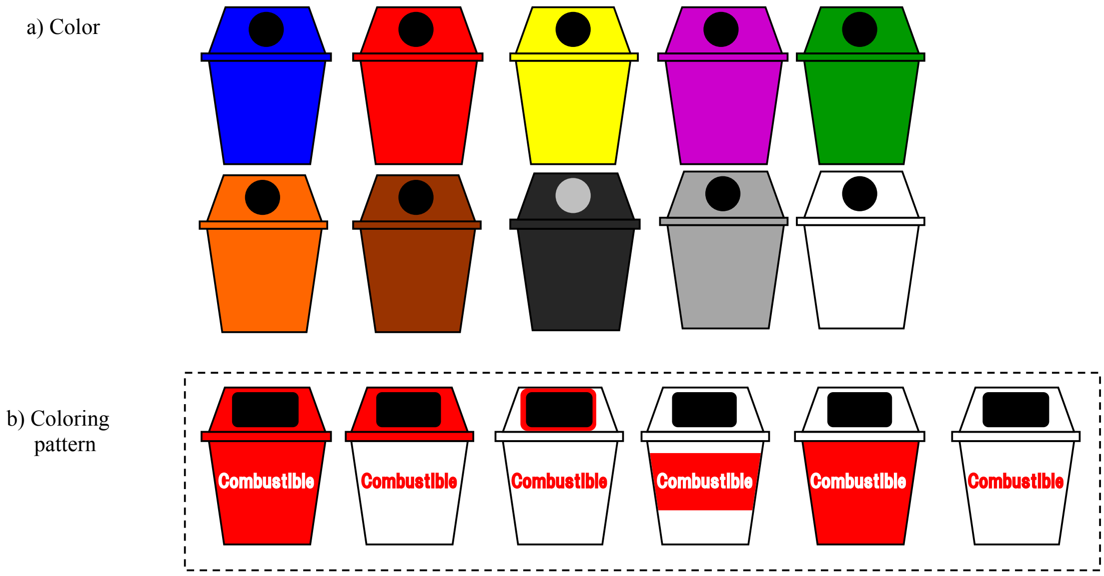


Figure 2–1. Recycling bin designs used in web-questionnaires: (a) Color preference, (b) Coloring pattern preference

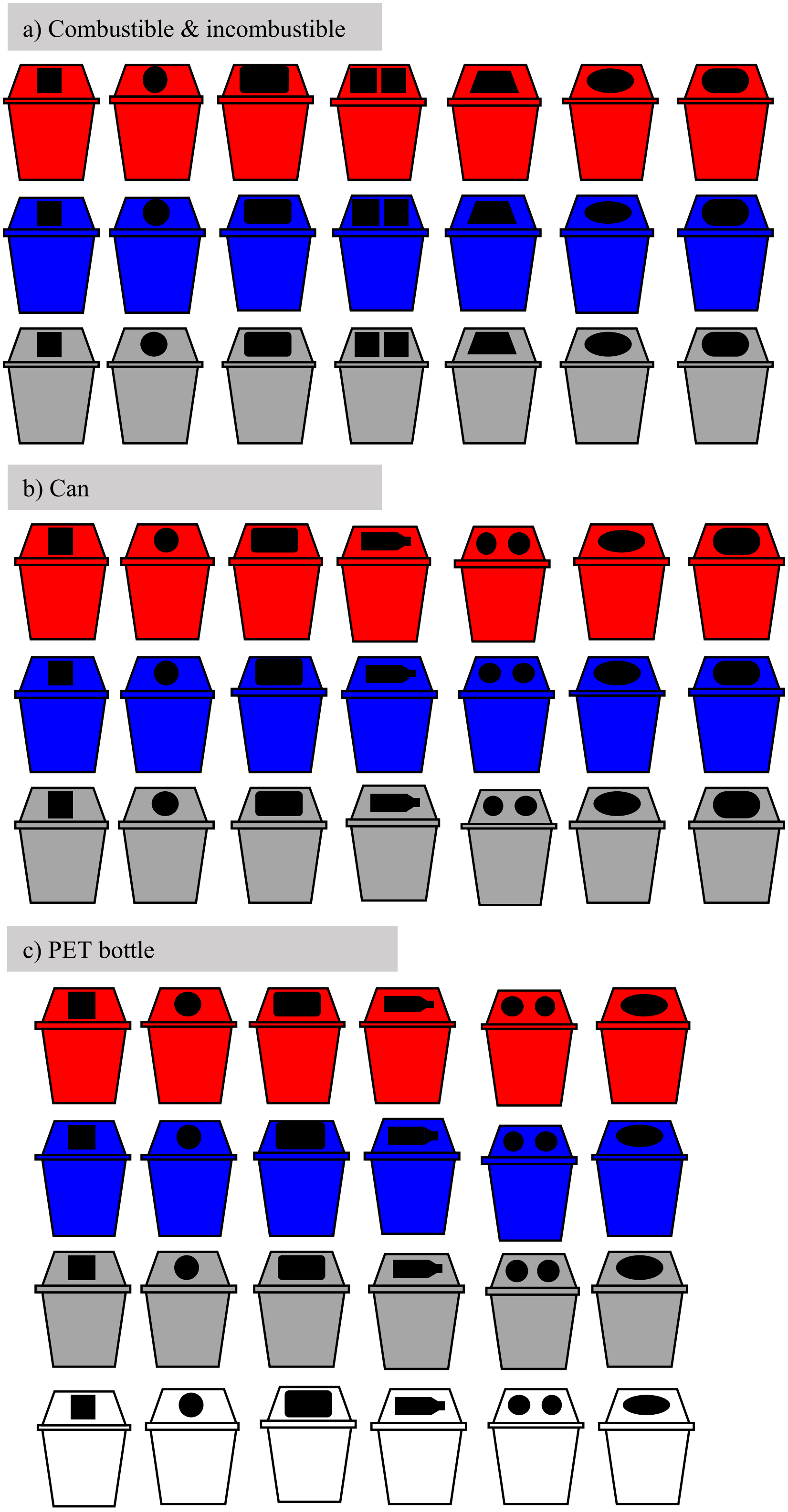
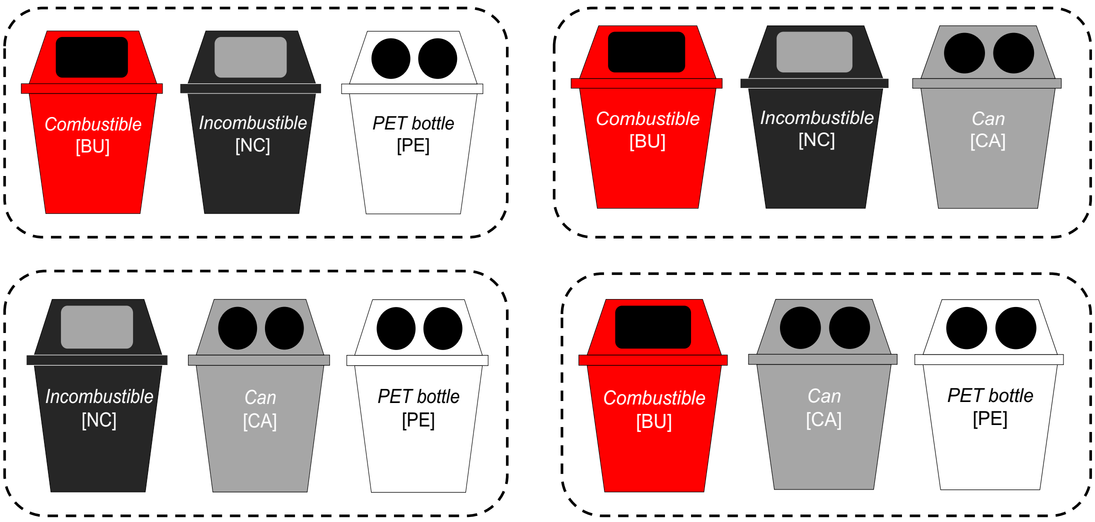


Figure 2–2. Designed recycling bin with different slot shape and different color: (a) Combustible and incombustible waste bins, (b) Can bins, (c) PET bottle bins

Figure 2–3.Designed recycling bin for combustible waste with different slot position

a) Three recycling bins



a) Four recycling bins

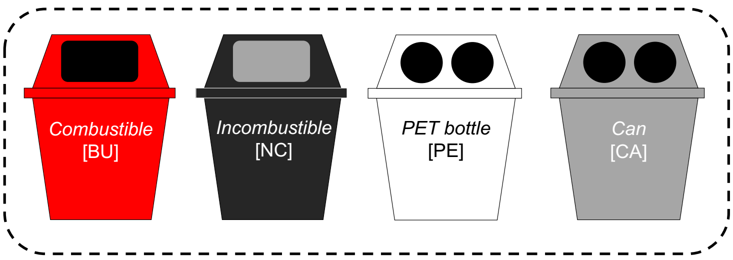


Figure 2–4.Arrangement of recycling bins: (a) Three recycling bins,(b) Four recycling bins

2.2.2 Pairwise comparison method

This study quantified perceptive preference toward design items of recycling bins by pairwise comparison method. In the questionnaire survey, all possible pairs of recycling bin illustrations with different design items were presented to the survey participants in random order. In all binary choices, the participants selected one recycling bin to which they felt higher preference. This method is designed based on a psychological model proposed by Thurstone (Thurstone, 1927). When two psychological stimuli are compared, a “discriminal process” associated to each stimulus invoked on a psychological continuum. The judgement between the two stimuli, which is a selection of more preferred recycling bin in this case, is driven by the rank produced by the discriminal processes (Cheng et al., 2013). Because psychological processing usually include uncertainty, 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 assumed to be normal Gaussian distribution. The concept of this model is shown in Figure 2-5. When Z_A and Z_B are design preference that the survey participants perceive to recycling bin A and recycling bin B, respectively, the difference between the two preferences, (Z_A - Z_B), has the relationship of a cumulative normal distribution with a selection ratio of recycling bin A (or recycling bin B). When the preference difference is larger, the selection ratio will increase or decrease correspondingly. When the two preferences are equal (no preference difference), it results in an equivalent selection ratio of each recycling bin (0.5). This study used case V of the initial condition, in which the expected value (or mean) of the preference difference was assumed zero and the variances of the discriminal dispersions of the two preferences were equal. The variance was set at 1.0, which is usual. As shown in Figure 2-5, the selection ratio could be inversely transformed to the difference between two preferences. The preference toward recycling bin A could be calculated from the average of all differences related to recycling bin A because of the initial condition of zero mean. In this study, a higher score means larger preference intensity.

2.2.3 Web-questionnaire survey

Web questionnaire surveys were conducted in September 2015 to March 2018 by QuickMill®, Macromill Inc., Japan. The numbers of survey participants, sample size (N), were 730 for color design preference, 730 for slot shape preference for PET bottle bins, 210 for slot shape preference for the other bins, 3090 for slot position preference and 630 for recycling bin arrangement. The participants were randomly selected and anonymous to the authors. The participants were pre-screened to obtain equal gender ratio and an equal age distribution with 10-year age intervals (20s, 30s, 40s, 50s and 60s).

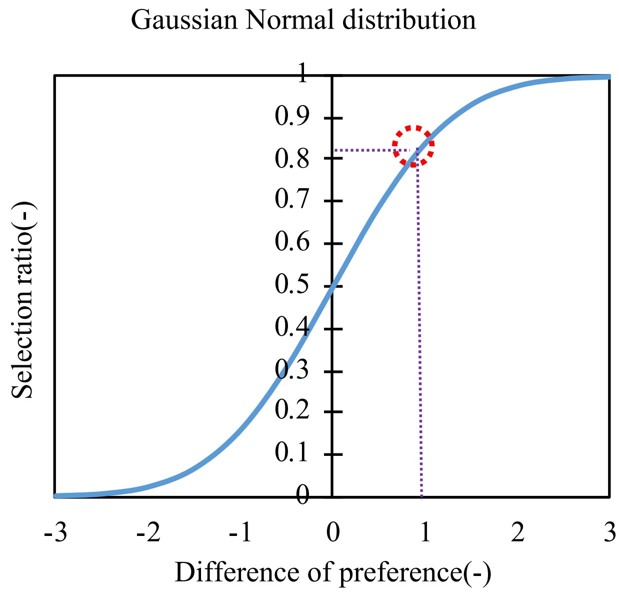


Figure 2–5. The concept of Thurstone's model

2.3 Results and discussion

2.3.1 Color preference measured by web-questionnaires

Figure 2-6 shows the preference scores of recycling bin colors for combustible waste, incombustible waste, can, and PET bottles. Higher score means higher preference. The color with higher preference lets people perceive "appropriate color" for target type of waste. As shown in Figure 2-6, the color preference toward each recycling bin is different from each other. In the case of combustible waste bins, red and orange are the most and the second most preferred colors. The one-sided paired t-test suggests that red is significantly preferred than orange with 0.5 % significance level. In addition, there are large gaps of the preference between red/orange and others. Gray and black are the most preferred for incombustible waste bins. As the same with preferred colors for combustible waste bins, there are large gaps between black/gray and other colors for incombustible waste bins. White and gray are specifically preferred for PET bottle bins. Gray, orange and blue are preferred for can bins. The highest preference of red color for combustible waste bins might be reasonable according to a strong color-concept stereotype between red and fire/flammable (Ng and Chan, 2018). In addition, Schloss et al proposed local association hypothesis, which predicts that people simply match objects with their most strongly associated color (Schloss et al., 2018). High similarity of orange color to red explains high preference for combustible waste bins. The highest preference of black and gray colors for incombustible waste bins is likely derived from "anti-fire" impression of these colors. It is supported by the worst preference of red color (fire color) for incombustible waste bins. The highest preference of white color for PET bottle bins might be derived from the transparency or no color of PET bottles. Green is the third preferred, following white and gray. This might be derived from the color of bottled green tea, which are popular in Japan beverage market, and/or high perceptive association of green color to recycle/environment-friendly (Montazeri et al., 2012). In fact, recycling rate of PET bottles is high in Japan (84.6 % in 2018). For can bins, the most preferred colors are gray, orange, and blue. It is difficult to explain what contributes into high preference of these colors for can bins. In this survey, gray is usually preferred for all types of wastes. In contrast, purple is not preferred regardless of waste type.

Figure 2-7 shows comparison between the design preferences toward combustible waste bins with different red coloring designs. The trend line was found among whole red-colored bin, half red-colored bin, and no red-colored (whole white) bin. It suggests that design preference increases linearly with the increase of red-colored area. On the other hand, recycling bin designs, which are red-colored around insert slot, have greatly higher preferences than other designs. It clearly shows that red color around insert slot can effectively increase design preference.

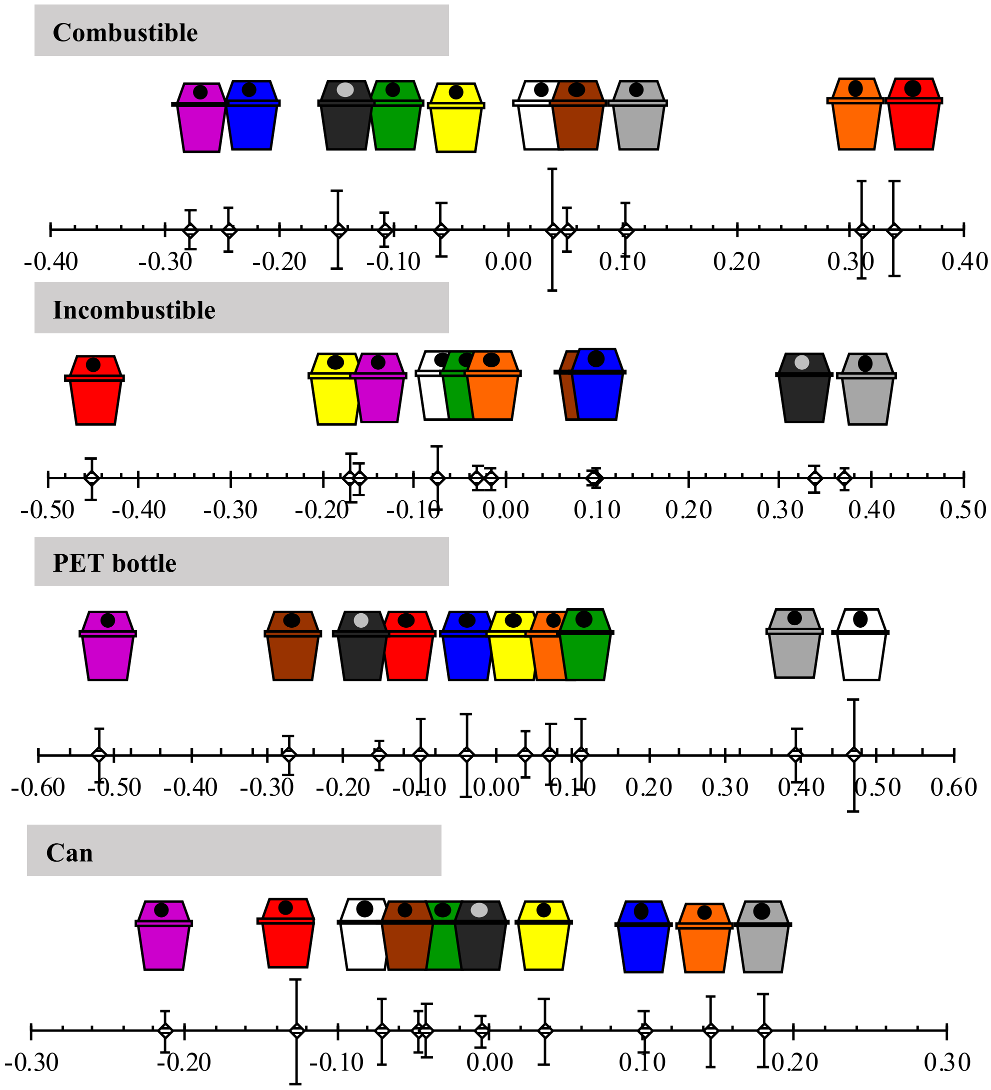


Figure 2–6. Scaled preference toward recycling bin colors (body color) for combustible waste, incombustible waste, PET bottle, and can

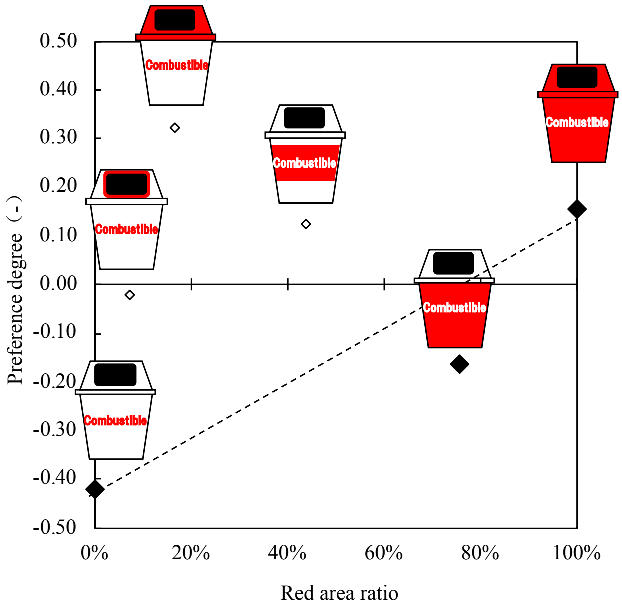


Figure 2–7.Comparison between design preferences toward combustible waste bins with different red coloring pattern (different red area ratios)

2.3.2 Preferences of insert slot shape and slot position

Figure 2-8 shows the preference scores of insert slot shapes for combustible waste bins, incombustible waste bins, can bins, and PET bottle bins. High preference score means that people perceive "appropriate" slot shape for target type of waste. Preferences of slot shape for combustible and incombustible waste bins are similar. The most preferred slot shape is rectangle and the second preferred slot shape is stadium. Trapezoid, ellipse, and two squares receive moderate preferences. On the other hand, single circle is the worst preferred design, followed by square. Figure 2-9 shows comparisons between preference scores of slot shapes and slot areas. The t-test suggests that preference score has a significantly positive trend with the increase of slot area for combustible waste bins ($p < 0.0001$, $1-\beta > 0.999$) and incombustible waste bins ($p < 0.0001$, $1-\beta > 0.999$). It is reasonable because larger slot area is easier to drop wastes, in particular large size waste, and thus might let persons perceive "appropriate" design. On the other hand, two-square shape is given exceptionally low preference compared with its relatively large slot area. It supports this hypothesis because a partition between two square slots causes the difficulty to drop large size waste.Preferred slot shapes for PET bottle bins and can bins are also similar. The most and the second preferred slot shape are two circles and one circle for both bins, respectively. For PET bottle bins, the other slot shapes are greatly less preferred than two circles/single circle. The worst preferred shape is square, followed by rectangle and ellipse. These results clearly suggest that rounded shape is more preferred than angular shape for insert slot of PET bottle bins. In general, rounded objects are preferred more than angular objects (Bar and Neta, 2006; 2007). On the other hand, it might be derived mainly from the similarity with the cross-section of PET bottles (usually round or semi-round shapes). Congruence with consumers' anticipated product shape is proposed as a determinant of aesthetic preference for graphic shapes (Fang and Mowen, 2005). Different from PET bottle bins, on the other hand, square slot shape receives high preference for can bins (the third preference). Therefore, it might not be reasonable to conclude that the rounded shapes are also preferred than angular shape for can bins.

Figure 2-10 shows the preference of combustible waste bins which have an insert slot with different positions (slope, front, and top). Slope position is the most preferred regardless of inner visibility. Top position is the second preferred and front position is the worst. An insert slot in slope position might be more noticeable and convenient for waste drop than the other positions. It might contribute into the highest preference of slop position.

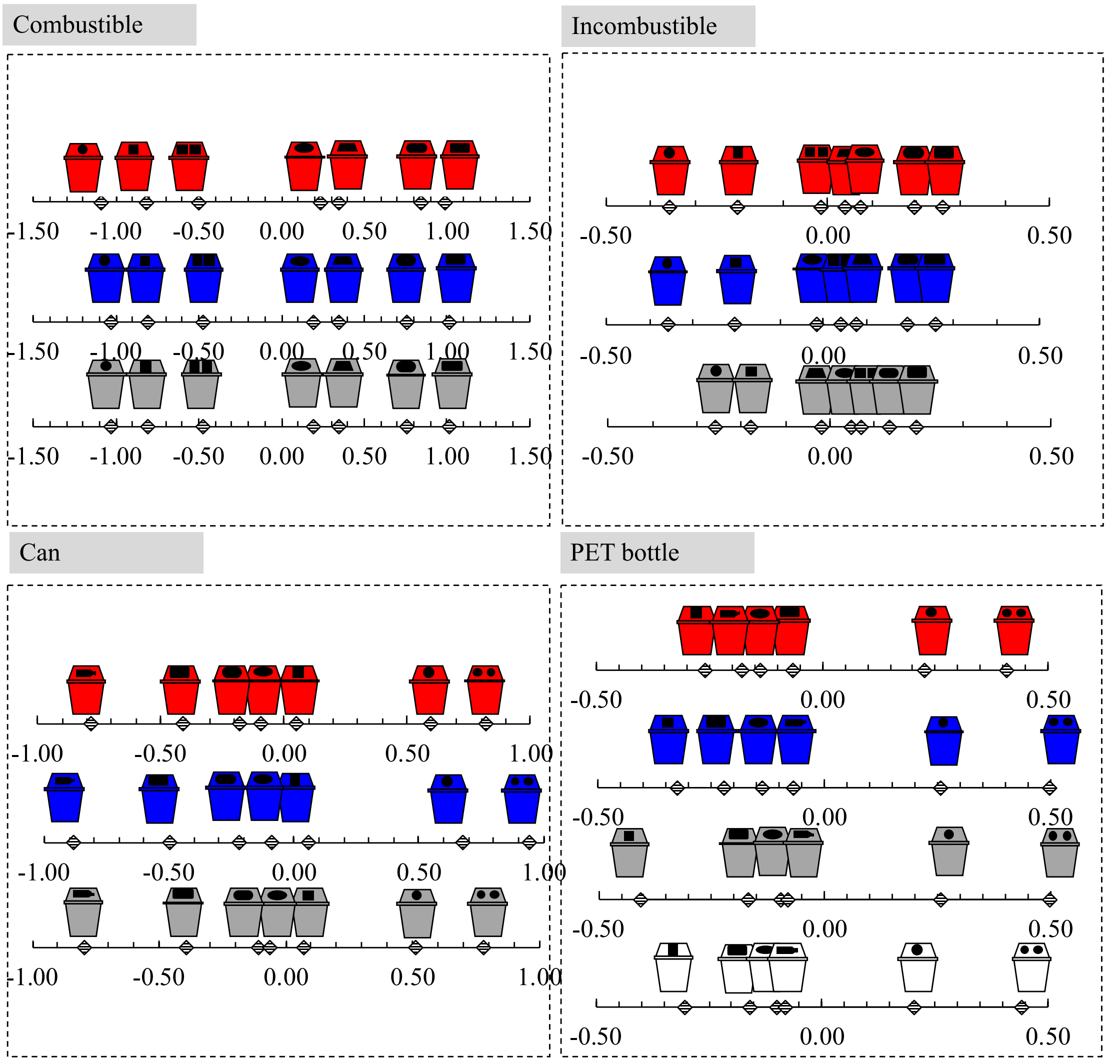


Figure 2–8. Scaled preference toward insert slot shapes for combustible waste bins, incombustible waste bins, PET bottle bins, and can bins

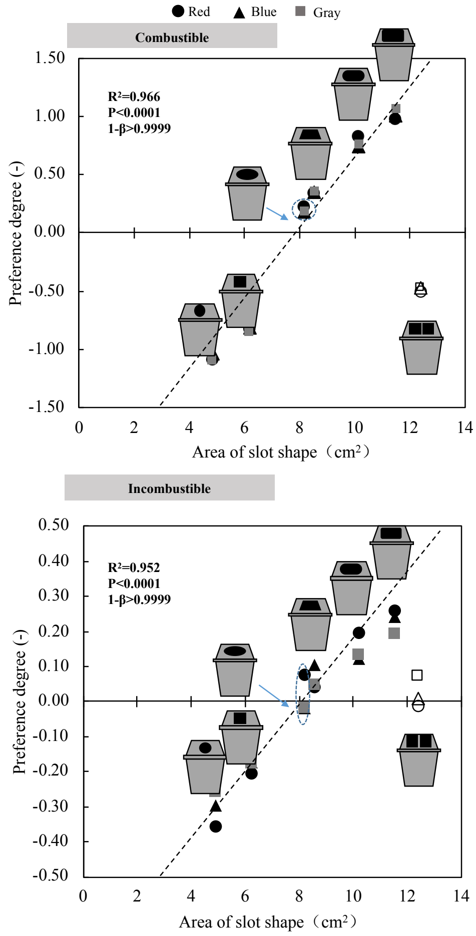


Figure 2–9. Comparisons between preferences toward slot shapes and slot areas for combustible waste bins and incombustible waste bins

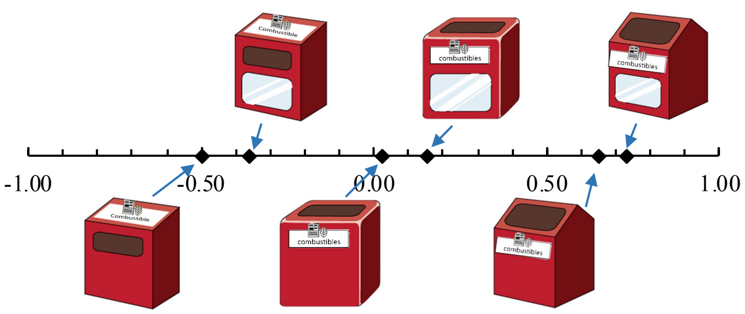


Figure 2–10. Scaled preference toward slot position for combustible waste bins

2.3.3 Preferences of arrangement

Table 2-1 shows the calculated preference degree of arrangements in three and four recycling bins. Z value is used to represent the preference degree of different arrangements. Higher Z value means higher preference degree. In other words, arrangement with high Z value is strongly preferred. In the case of three recycling bins, the most preferred arrangement is combustible waste container, incombustible waste container and PET bottle container set from the left to the right. The first six preferred arrangements show the preferred set in three recycling bins is the recycling bin combination of combustible, incombustible and PET bottle containers. In addition, recycling container arrangement including combustible waste container are more preferred than the others. The results indicated the demand for the recycling bin is combustible waste container > incombustible waste container > PET bottle container > can container. It can be explained by the different waste generation in our daily life. Combustible and incombustible waste are the main waste, and generation of combustible is larger than incombustible waste. As the drink containers, PET bottle consumption is bigger than the can consumption in Japan. At the same time, combustible waste container on the left side is preferred in the 3 and 4 recycling bins case. This preference is more significant in the case of four recycling bins. It is found in the most preferred six arrangements. Incombustible waste container on the left is preferred if no container of combustible wastes in three recycling bin case. When the combustible wastes container is not on the left, incombustible wastes container on the left is also preferred in four recycling bins case. It indicates people prefer the more necessary recycling bin set on the left. In four recycling bins case, the most preferred arrangements of recycling bins are combustible, incombustible, PET bottle and can containers from the left to the right, which is similar to the three recycling bins case. Combustible waste container besides the incombustible waste container is preferred. In addition, PET bottle container beside Can container is also preferred because they are both recyclable resources. Most people are used to separate waste according to the sequence from combustible waste, incombustible waste to the recyclable resource.

Table 2–1. Preference degree (Z value) of different recycling container arrangements

	3 recycling bins		4 recycling bins	
Order	Arrangement	Z value	Arrangement	Z value
1	BU-NC-PE	0.696	BU-NC-PE-CA	0.666
2	BU-PE-NC	0.381	BU-NC-CA-PE	0.636
3	NC-BU-PE	0.281	BU-PE-NC-CA	0.269
4	NC-PE-BU	0.185	BU-PE-CA-NC	0.356
5	PE-BU-NC	0.375	BU-CA-NC-PE	0.148
6	PE-NC-BU	0.410	BU-CA-PE-NC	0.274
7	BU-NC-CA	0.486	NC-BU-PE-CA	0.123
8	BU-CA-NC	0.143	NC-BU-CA-PE	0.010
9	NC-BU-CA	0.056	NC-PE-BU-CA	-0.490
10	NC-CA-BU	-0.066	NC-PE-CA-BU	-0.205
11	CA-BU-NC	0.113	NC-CA-BU-PE	-0.515
12	CA-NC-BU	0.161	NC-CA-PE-BU	-0.192
13	BU-CA-PE	0.340	PE-BU-NC-CA	-0.017
14	BU-PE-CA	0.349	PE-BU-CA-NC	-0.342
15	CA-BU-PE	-0.154	PE-NC-BU-CA	-0.220
16	CA-PE-BU	0.093	PE-NC-CA-BU	-0.338
17	PE-BU-CA	-0.110	PE-CA-BU-NC	0.035
18	PE-CA-BU	0.097	PE-CA-NC-BU	0.220
19	NC-PE-CA	-0.527	CA-BU-NC-PE	-0.047
20	NC-CA-PE	-0.562	CA-BU-PE-NC	-0.417
21	PE-NC-CA	-0.724	CA-NC-BU-PE	-0.172
22	PE-CA-NC	-0.603	CA-NC-PE-BU	-0.271
23	CA-NC-PE	-0.771	CA-PE-BU-NC	0.180
24	CA-PE-NC	-0.648	CA-PE-NC-BU	0.309

*Waste type abbreviation

BU: Combustible wastes (Burnable)

NC: Incombustible wastes (Non-combustion)

PE: PET bottles

CA: Cans

2.4 Conclusion

Color, slot shape, slot position and arrangements of recycling bins can give different preferences to users and they were measured by pairwise comparison method. The most preferred colors of recycling bins are red for combustible waste, black for incombustible waste, blue for can and white for pet bottles, respectively. The most preferred slot shapes are rectangle for combustible and incombustible, two circles for PET bottle and can, respectively. People preferred combustible waste container on the left side and incombustible waste container in the next position. Recyclable wastes (PET bottle and can) containers on the right side are also preferred. Appropriate design and arrangement of recycling bins might be able to encourage users to separate wastes psychologically.

Chapter 3 The comparison between the design preference and real recycling bins

3.1 Introduction

In this context, the impact of perception frequency of recycling bin designs on design preference was concerned in this study. To investigate it, this study surveyed the popularity of design items for real recycling bins used in public sites. Potential association of usual experiences to perceive real designs of recycling bins in daily life with design preference were discussed. The effect of one design item on waste segregation was also verified by waste collection experiments.

3.2 Recycling bin collection and category from Japan

In this study, 240 of recycling bins used in public places in Japan, like train stations, convenience stores, supermarkets, public gardens, and others, were observed for design categorization analysis. They were 51 combustible waste bins, 28 incombustible waste (including plastic) bins, 80 PET bottle bins, and 81 can bins. Recycling bin designs were categorized according to color and insert slot design. The color categorization included body color of a recycling bin, signage color, and slot frame color. Signage color was further categorized by signage background color, signage text color, and pictogram color. The insert slot was categorized based on slot shape and position (top, slope, and front). It is noted that slot frame color was identified and recorded when it was different from body color. The categorization data was transformed to observation frequency rate (appearance rate) for design analysis.

3.3 Results and discussion

3.3.1 Categorization of real recycling bin in Japan

3.3.1.1 Color categorization

Figure 3-1 shows the color distribution of each design item for real waste bins used in common sites in Japan. According to the averages of color appearance rates for all waste bins, major colors used for real recycling bin designs were white, black, blue, red, gray, green and yellow. Regardless of waste type (combustible waste, incombustible waste, PET bottle and can), recycling bins always had similar coloring design in container body. In particular, white and gray (or sliver) were major popular colors for recycling bin body. On the other hand, the design differences were found in signage color and slot frame color depending on waste type. As mentioned in the section 3.1, the signage colors were separately categorized to signage background color, signage word color, and pictogram color. Black and white were mainly used for the signage word color for all waste types. In addition, white and black colors were also used for signage background and pictogram with similar percentages. High contrast between black and white is helpful to recognize the signage (Hall and Hanna,2004). It probably encourages using white and black as basic colors. The color distribution of recycling bins for different waste type will be discussed in signage color and slot frame color respectively.

1) **Signage colors:** In signage design, background and pictogram usually cover larger area than text. They are usually more effective than text in terms of recycling bin users' perception (Punchoojit and Hongwarittorrn, 2018; Wu et al., 2018). Therefore, signage background color and pictogram color are important to help users distinguish waste type. According to Figure 3-1, the color distributions of signage background and pictogram of recycling bins for each waste type are similar. For combustible waste bins, red was used more frequently than that for other waste bins. Gray, blue, and yellow were mainly used for incombustible waste bins. Yellow, blue, and green were popular for PET bottle bins. Blue and gray were used frequently for the can bin. Green mainly appeared in the design of PET bottle bins and can bins.
2) **Slot frame colors:** In terms of slot frame color, single color was usually used and multi-colored slot frame was not observed. Red was mainly used for slot frame of combustible waste bins (see Figure 3-1). Exceptionally, red slot frame was observed in only one incombustible waste bin. It was not observed for PET bottle bins and can bins in this survey. For not only slot frame color but also signage color (signage

background, word, and pictogram), red was the main color used for combustible waste bins. Gray slot frame appeared in all waste type bins. In particular, incombustible waste bins had the highest percentage of gray slot frame among them. Blue slot frame was also widely observed for incombustible waste bins, PET bottle bins, and can bins. In particular, can bins had the highest percentage. Yellow slot frame was observed for incombustible waste bins and PET bottle bins. Green slot frame shows similar percentage among incombustible waste bins, PET bottle bins, and can bins. A PET bottle bin and a can bin are commingled in most cases. Therefore, the blue frame slot shows both the largest appearance percentage for both PET bottle bins and can bins. As reported above, yellow slot frame was observed for PET bottle bins and not for can bins. It indicates that blue was used for the can bin and yellow was mainly used for the PET bottle bin when PET bottle/can bins are comingled. They are summarized that major colors used for slot frames were red for combustible waste bins, gray for incombustible waste bin, yellow for PET bottle bins, and blue for can bins, respectively.

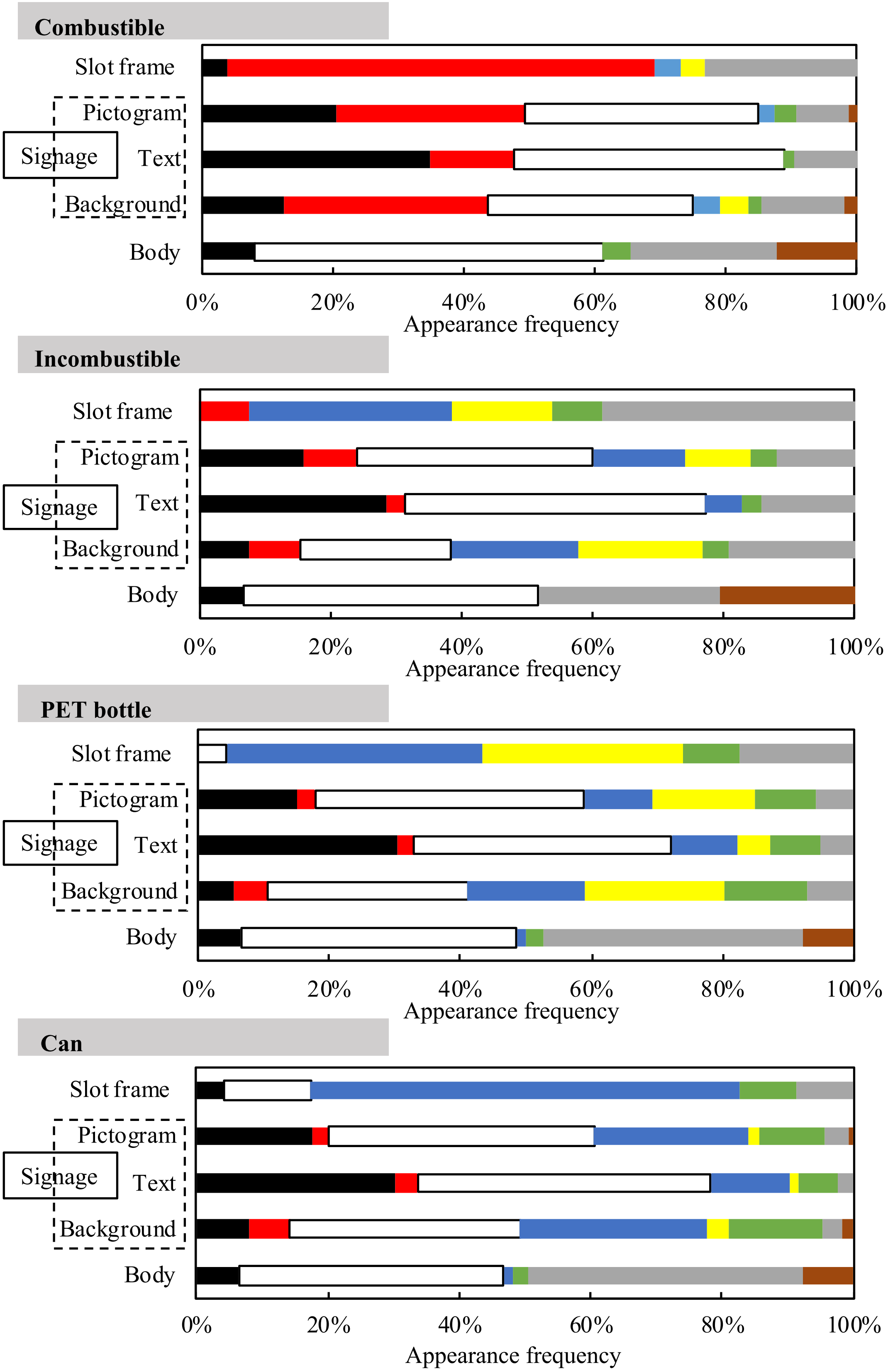


Figure 3–1. Color appearance frequency of combustible waste bins, incombustible waste bins, PET bottle bins, and can bins

3.3.1.2 insert slot categorization

Figure 3-2a shows appearance percentage of insert slot shape of real recycling bins. For combustible and incombustible waste bins, the results are similar. The most observed slot shape is rectangle. Its appearance rates are 70 % for combustible waste bins and 61 % for incombustible waste bins, respectively. The second most frequently observed slot shape is stadium (18 % for combustible waste bins and 14% for incombustible waste bins). For PET bottle bins, slot shapes with high appearance percentage to low one are two circles, rectangle, single circle, two squares, single square, stadium, and the others. For can bins, the most observed slot shape is two circles (69 %) and the second most observed slot shape is circle (16 %). Figure3-2b shows appearance rates of insert slot position. In general, slope position was observed more than front and top positions regardless of waste type. The Tukey-Kramer multiple comparison test proposes that the differences are statistically significant ($p = 0.0241$ for slope/front and $p = 0.0113$ for slope/top). On the other hand, no significant difference of appearance percentage between front and top positions was found. Waste type also produced no significant difference in terms of insert slot position.

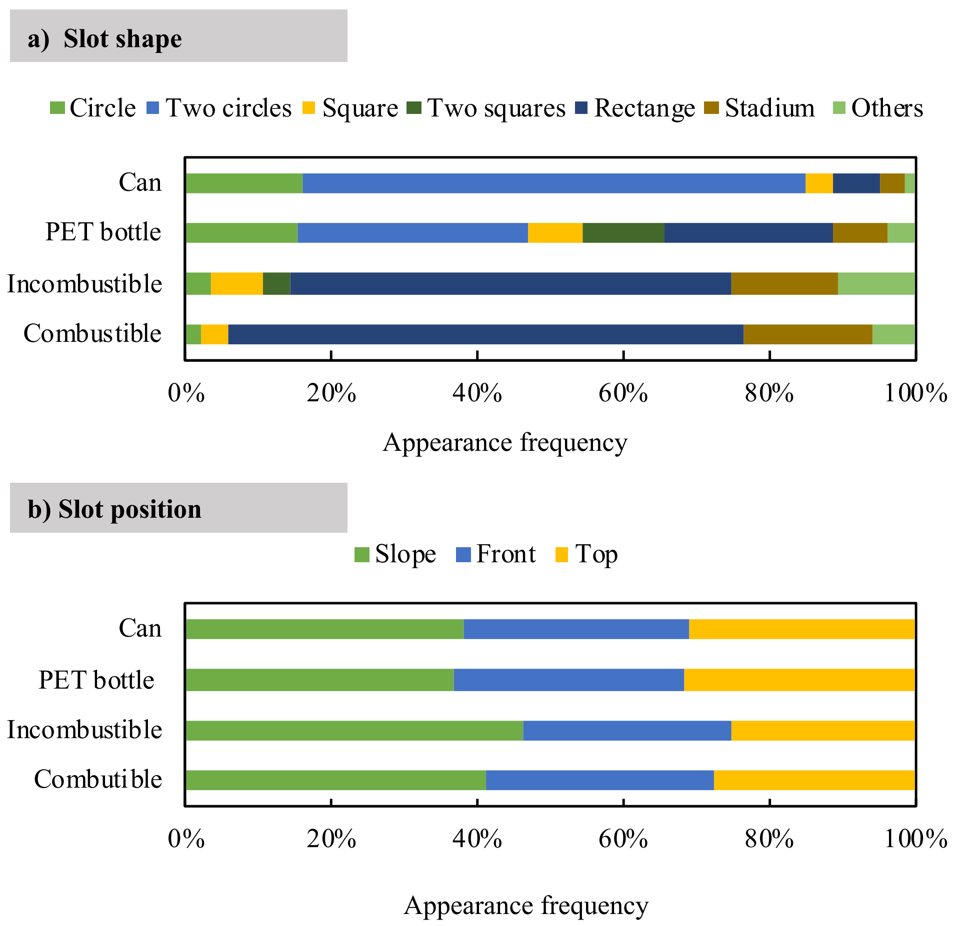


Figure 3–2. Appearance frequency of slot design items in real recycling bins: (a) Slot shape, and (b) Slot position

3.3.2 Comparisons between perception preference and appearance frequency of design items

3.3.2.1 The impact of past experiences on color preference

Table 3-1 summarizes the colors from the best preferred to the worst for each waste type bin and color appearance percentages of real recycling bins for all design categories. In the case of combustible waste bins, the most preferred color (red) is used the most in slot frame. It is also the same for incombustible waste bins.

Table 3–1. Color preference toward and color appearance percentages of real recycling bins for all design items

Combustible						
Color preference		Color share of real trash bin				
		Body	Slot frame	Signage		
				Background	Text	Pictogram
red	0.3385	0%	65%	29%	16%	49%
orange	0.3098	0%	0%	0%	0%	0%
gray	0.1025	22%	23%	12%	12%	14%
brown	0.0514	10%	0%	2%	0%	2%
white	0.0391	51%	0%	29%	51%	61%
yellow	-0.0588	0%	4%	4%	0%	0%
green	-0.1090	4%	0%	2%	2%	6%
black	-0.1497	8%	4%	12%	43%	35%
blue	-0.2450	0%	4%	4%	0%	4%
purple	-0.2786	0%	0%	0%	0%	0%
Incombustible						
Color preference		Color share of real trash bin				
		Body	Slot frame	Signage		
				Background	Text	Pictogram
gray	0.3703	28%	38%	18%	18%	21%
black	0.3380	7%	0%	7%	36%	29%
blue	0.0988	0%	31%	18%	7%	25%
brown	0.0952	10%	0%	0%	0%	0%
orange	-0.0165	0%	0%	0%	0%	0%
green	-0.0301	0%	8%	4%	4%	7%
white	-0.0747	45%	0%	21%	57%	64%
purple	-0.1599	0%	0%	0%	0%	0%
yellow	-0.1684	0%	15%	18%	0%	18%
red	-0.4527	0%	8%	7%	4%	14%
PET Bottle						
Color preference		Color share of real trash bin				
		Body	Slot frame	Signage		
				Background	Text	Pictogram
white	0.4689	41%	4%	22%	39%	56%
gray	0.3942	38%	17%	5%	5%	8%
green	0.1106	3%	9%	9%	8%	13%
orange	0.0720	0%	0%	0%	0%	0%
yellow	0.0385	0%	30%	15%	5%	22%
blue	-0.0393	1%	39%	13%	10%	14%
red	-0.0991	0%	0%	4%	3%	4%
black	-0.1534	6%	0%	4%	30%	20%
brown	-0.2725	5%	0%	0%	0%	0%
purple	-0.5198	0%	0%	0%	0%	0%
can						
Color preference		Color share of real trash bin				
		Body	Slot frame	Signage		
				Background	Text	Pictogram
gray	0.1795	40%	9%	2%	2%	5%
orange	0.1447	0%	0%	0%	0%	0%
blue	0.1011	1%	65%	22%	12%	35%
yellow	0.0358	0%	0%	2%	1%	2%
black	-0.0058	6%	4%	0%	0%	0%
green	-0.0414	2%	9%	11%	6%	15%
brown	-0.0467	6%	0%	1%	0%	1%
white	-0.0704	38%	13%	27%	46%	59%
red	-0.1272	0%	0%	5%	4%	4%
purple	-0.2126	0%	0%	0%	0%	0%

Gray is the most preferred and used the most frequently in slot frame as well as container body. On the other hand, the most preferred color is consistent with the most frequently used color in container body, not in slot frame, for PET bottle bins and can bins. For PET bottle bins, white and gray are the first and the second preferred colors as well as the most and the second most used colors in container body. For can bins, gray is the most preferred and the most used in container body. These agreements propose potential associations between color preference and color appearance rate of certain design item. It will be discussed in the next section.

It should be noted that certain colors which received moderate or high preferences were not observed in real recycling bin designs. For example, orange is the second preferred color for both combustible waste bins and can bins but not observed in any design items. For incombustible waste bins, the worst preferred color (red) has similar appearance rate in signage design with blue which is the third preferred color. For PET bottle bins and can bins, green and yellow showed contradictory relations between color preference and color appearance rate. For PET bottle bins, green is more preferred than yellow but less used in slot frame and signage designs. On the other hand, green is less preferred but more used than yellow for can bins. Except for certain design items, it is concluded that color appearance rate is not associated with color preference.

As described in the chapter 1, color can facilitate object recognition (Clarke and Ludington, 2018). For example, color preference is significant in the selectin of appropriate recycling bin (Kalatzi et al., 2015). A bright yellow cover of recycling bin can improve the capture rate of food waste (Lin et al., 2016). They might be explained by strong association between the color preference and waste type (Schloss et al., 2018). On the other hand, opportunity frequency of design perceptions or information exposure can affect design preference (Cox and Cox, 2002). It suggests that the color preference toward recycling bin design might be affected by frequent visual perception of real recycling bins. In particular, it is hypothesized that the color of certain design items of recycling bins might be so impressive that it is strongly associated with color preference. For combustible/incombustible waste bins, the comparisons in the previous section suggest the color of slot frame as impressive one. On the other hand, impressive color is body color of recycling bins for PET bottle and can. A statistical test (t-test) supports this hypothesis. As shown in Figure 3-3, color appearance frequency of slot frame has significantly positive correlation with color preference for both combustible waste bins ($p = 0.009$, $1-\beta = 0.997$) and incombustible waste bins ($p = 0.032$, $1-\beta = 0.867$). A significant correlation also found between color preference and appearance frequency of body color for PET bottles ($p = 0.012$, $1-\beta = 0.993$). For can bins, the correlation was regarded insignificant ($p = 0.314$, $1-\beta = 0.135$). The result of chapter 2, the design preferences toward combustible waste bins with different red coloring designs, as shown in Figure 2-7, also supports the importance of insert slot color for design preference. Although the proposed hypothesis should be verified further, coloring on certain design items, depending on waste type, might be effective to increase design preference and it might improve waste segregation. The impact of bin coloring on waste segregation will be discussed in following chapter 4.

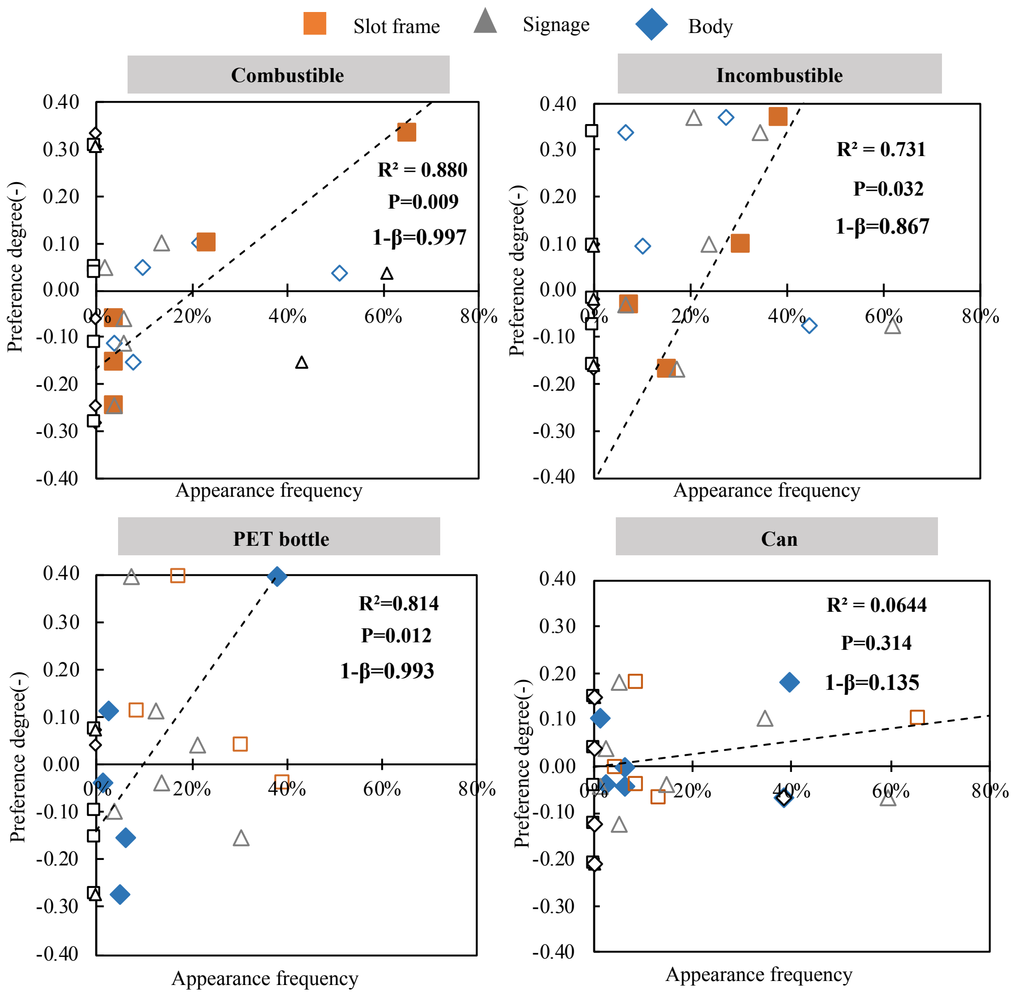


Figure 3–3. Comparisons between color preference and color appearance frequency in real recycling bins (combustible waste, incombustible waste, PET bottle, and can)

3.3.2.2 The impact of past experiences on preferences toward slot shape and slot position

Table 3-2 summarizes the preference of slot shape for each waste type bin with different body color and appearance percentages of slot shape for real recycling bins. For combustible and incombustible waste bins, the most and the second most preferred slot shapes (rectangle and stadium) are the same with the most frequently and the second frequently observed slot shapes in real recycling bins. For PET bottle and can bins, the most preferred shape (two circles) is also consistent with the most frequently observed slot shape. Good agreement between preferred slot shapes and frequently observed slot shapes in real recycling bins suggests that perceptive preference toward slot shape might be mainly derived from daily experiences, in particular many perception opportunities of recycling bins with two circles or single circle insert slot. When slot shapes with appearance rate higher than 2% are selected, moderate correlations were found between preferences and appearance rates (see Figure 3-4). It partially supports the hypothesis. On the other hand, some shapes with high preference have zero appearance rate, in particular for combustible and incombustible waste bins. For these bins, slot shape preferences were mainly controlled by slot area (see Figure 2-9). In the case of slot position, the most preferred position (slope) is the same with the most frequently observed position in real recycling bins. In addition, significant correlation between the preference and observation percentage was also found, as shown in Figure 3-5. It partially supports the hypothesis that slot position preference is affected by past perception of real recycling bin designs. However, further survey is necessary for other waste bins to verify the hypothesis

Table 3–2. Slot shape preference toward and color appearance percentages of real recycling bins for all design items

Combustible					Incombustible				
Slot shape preference				Share of real trash bin	Slot shape preference				Share of real trash bin
Shape	Body color				Shape	Body color			
	Red	Blue	Gray			Red	Blue	Gray	
Square	-0.8172	-0.8098	-0.8435	4%	Square	-0.2041	-0.1714	-0.1769	7%
Circle	-1.0895	-1.0307	-1.0863	2%	Circle	-0.3564	-0.2943	-0.258	4%
Rectangle	0.9904	1.0157	1.0828	71%	Rectangle	0.2606	0.2442	0.1952	61%
Two squares	-0.5049	-0.4723	-0.4662	0%	Two squares	-0.013	0.0094	0.0716	4%
Trapezoid	0.3455	0.3497	0.3584	0%	Trapezoid	0.0408	0.106	0.0501	0%
Ellipse	0.232	0.1888	0.185	0%	Ellipse	0.0765	-0.0182	-0.0173	0%
Stadium	0.8436	0.7586	0.7699	18%	Stadium	0.1955	0.1243	0.1352	14%

Can					PET bottle					
Slot shape preference				Share of real trash bin	Slot shape preference					Share of real trash bin
Shape	Body color				Shape	Body color				
	Red	Blue	Gray			Gray	Blue	Red	White	
Square	0.0692	0.0584	0.0495	4%	Square	-0.3878	-0.3252	-0.2579	-0.3047	
Circle	0.5121	0.6758	0.5958	16%	Circle	0.2642	0.256	0.2265	0.2043	15%
Rectangle	-0.3929	-0.4961	-0.4106	6%	Rectangle	-0.1471	-0.2222	-0.1769	-0.1597	23%
Bottle	-0.7969	-0.8806	-0.7847	0%	Bottle	-0.113	-0.0676	-0.1383	-0.1003	0%
Two circles	0.7809	0.9457	0.8227	69%	Two circles	0.4594	0.4982	0.4097	0.4417	32%
Ellipse	-0.0637	-0.087	-0.094	0%	Ellipse	-0.0757	-0.1391	-0.0632	-0.0813	0%
Stadium	-0.1088	-0.2162	-0.1785	4%						

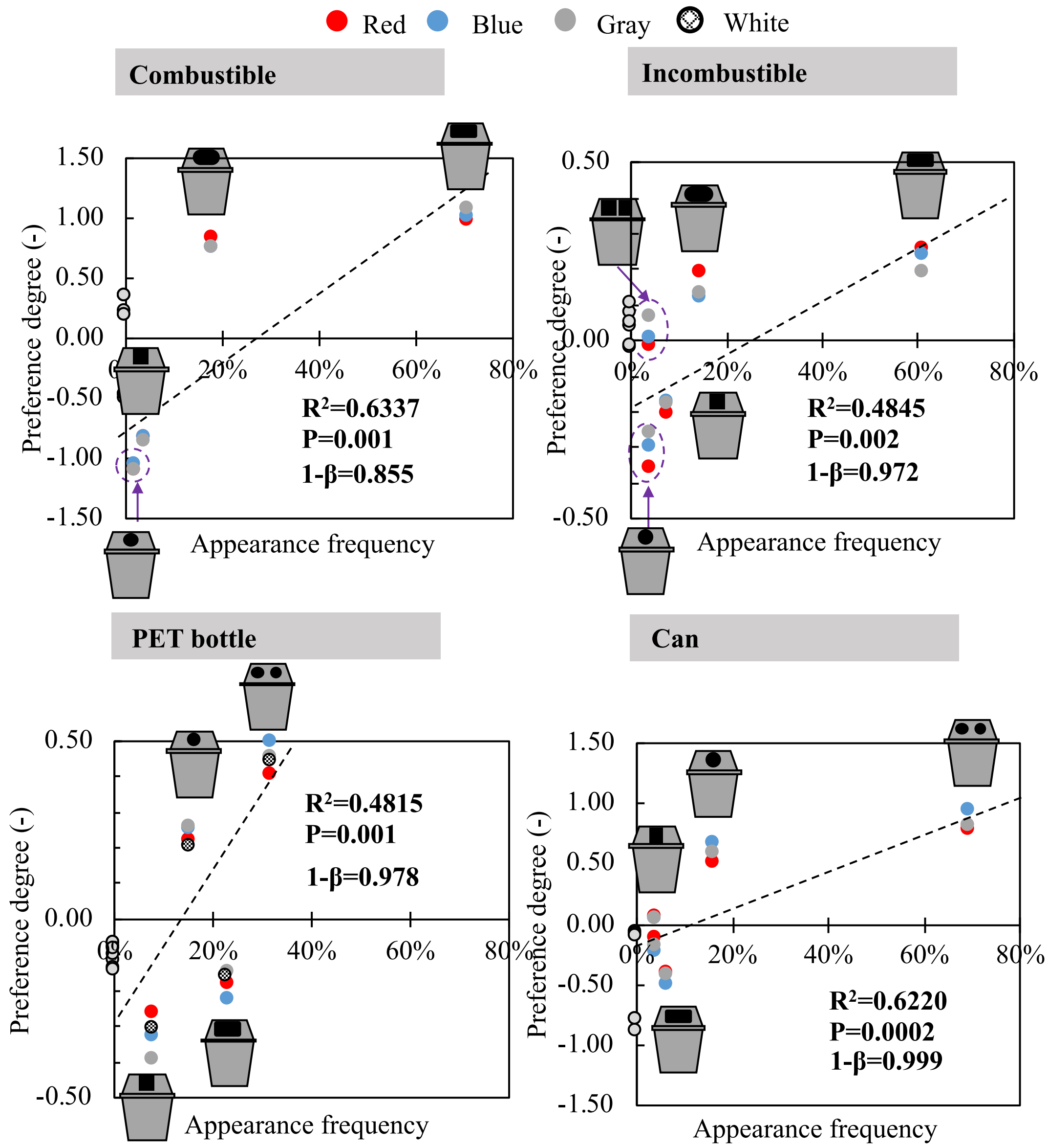


Figure 3–4. Comparisons between slot shape preference and appearance frequency in real recycling bins

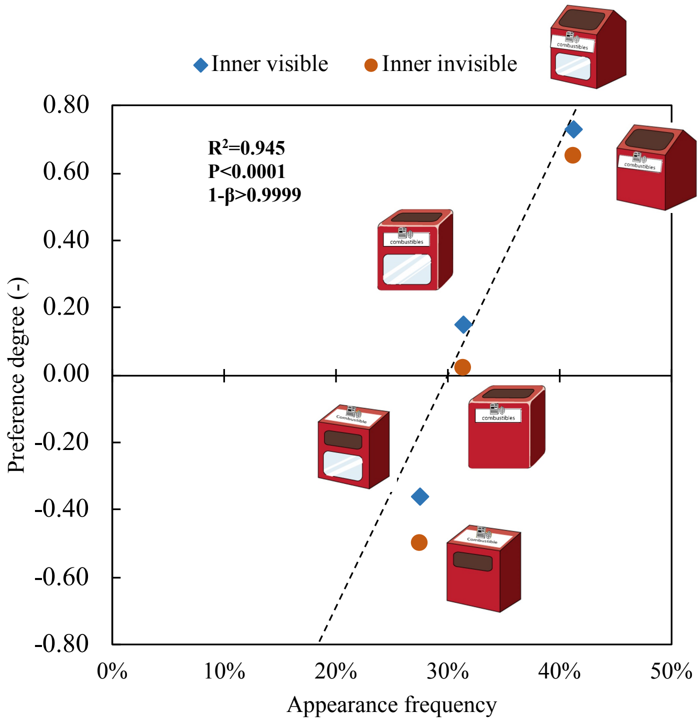


Figure 3–5. Comparison between slot position preference and appearance frequency for combustible waste bins

3.4 Conclusion and recommendation

Design categorization survey for 240 recycling bins used in public spaces shows that popular colors depend on design items and waste types. White and gray (or sliver) were major colors for recycling bin body. For signage designs, the color distributions of signage background and pictogram are similar regardless of waste type. On the other hand, major colors used for slot frames were red for combustible waste bins, gray for incombustible waste bin, yellow for PET bottle bins, and blue for can bins, respectively. This study found that highly preferred colors were consistent with frequently used colors in slot frame for combustible and incombustible waste bins, and body colors for PET bottle bins. In addition, there was a statistically significant correlation between color preferences and color usage rates. It is proposed that color used in certain item is so impressive that it affects color preference. Design preferences toward different red-colored recycling bins supports this hypothesis. In the case of insert slot shape, good agreements were also found between frequently used slot shapes and highly preferred shapes. Larger and angular shapes were preferred for combustible and incombustible waste bins. On the other hand, rounded shapes were popular for PET bottle/can bins. A significant correlation was also found for insert slot position between position preferences and slot position rates. According to significant correlation between design preferences and design usage rate in real recycling bins, this study proposes that design preference toward recycling bins is affected by past perceptions of recycling bin designs. On the other hand, when the design items have strong associations to waste items, it will leave deep impression on users. For example, the red color for combustible and the round insert for PET bottle and can. Possible recycling bin design has associations with waste items are recommend for the further study.

Recommendation

For the recycling bin design in Japan, this research recommends using different colors to represent different waste items, preferably be reflected in the slot frame. Because the body of the recycling bins mainly uses gray and white in daily life, gray and white slot frames are not recommended for all waste items. For combustible waste, red is the recommended color. It also has a high degree of preference and frequency of use. Therefore, the use of gray in combustible waste needs to be reduced. For the same reason, we recommend using black for incombustible waste, green for PET bottles and blue for can, respectively.

Chapter 4 Impact of recycling bin color and location on waste collection and separation

4.1 Introduction

The location of recycling bins is a critical factor which affects waste collection performance of recycling bins (O'Connor et al., 2010). Aras and Anarat suggested the recycling bins should be put near the place where high generation of recyclable materials are expected (Aras and Anarat, 2016). In this study, the connection between perceptive resistance (botheration) to take and drop wastes to a recycling bin with the distance to the recycling bin will be discussed. According to the effect of recycling bin design, in particular coloring around insert slot (in Chapter 3), on waste segregation, waste collection experiments were conducted to investigate not only the impact of the distance to trash bins on waste collection but also bin color effect on waste segregation. Therefore, the color impact on waste segregation and distance impact on collection will be analyzed in this chapter.

4.2 Distance botheration

4.2.1 Two processes in botheration quantification method

The method to quantify perceptive botheration consists of two steps. In the first step, the botheration of actions is quantified by web-questionnaire using binary pairwise comparison method, of which the same concept with preference quantification method. On the other hand, there is a difference from the preference quantification method. The questionees were presented two actions to quantify the botheration. They were requested to answer which action they felt more reluctant to do. In the pairwise comparison, reference actions were chosen from common behaviors in daily life (see Table 4-1). The other action for comparison is taking waste to the recycling bin along with different distance. To support the comparison, photos, in which recycling bins were set with different distances, were presented to the respondents. I selected four main places from Suzukakeidai campus of Tokyo Institute of Technology, took a series of photos of recycling bins with different distance view. The four places were the second and the third floor of J2 building, Suzukakeidai Honmu, and co-op shop. They are denoted as A, B, C, D in Figure 4-1. In each place, photos were taken far from recycling bins in 2, 4, 6, or 10 meters.

In the second step, quantified botheration was transformed to price value based on the correlation between quantified botheration of reference actions and market prices to outsource reference actions. For example, if people want to wash a car but don't want to do it, they pay fee to use car washing machine (outsourcing cost). When quantified botheration of reference actions and their outsourcing costs were compared, three singles logarithmic linearities were found (see Figure 4-2). However, it is difficult to offer a reasonable explanation why three singles logarithmic linearities appeared. Different market competitions of reference actions might contribute into this different single logarithmic linearities. Market prices of products and services usually depend on raw material costs, manufacturing costs, employment costs, profits, and others. If the market is more competitive, profits should decrease correspondingly and will be zero in completely competitive market. However, real markets are not completely-competitive and products/services providers can gain some profits in the market. It might cause different outsourcing costs (market prices) of reference actions which receive almost equal unwillingness. In this study, the middle logarithmic linearity curve (Eq.3) was used to transform quantified botheration to price value (JPN yen).

$$\boldsymbol{Y} = \mathbf{3.416} \times \mathbf{EXP}(\mathbf{2.292} \times \mathbf{X})\ (\mathbf{Eq.1})$$

Where Y is the botheration in Japanese yen and X is the botheration in Z value.

It should be noted that the main purpose of this chapter is to investigate the connection between perceptive resistance (botheration) to take and drop wastes to a recycling bin with the distance to the recycling bin as well as distance impact on waste collection. Even if estimated botheration includes certain errors, it would have caused no critical bias in correlation analysis between the distance and botheration.

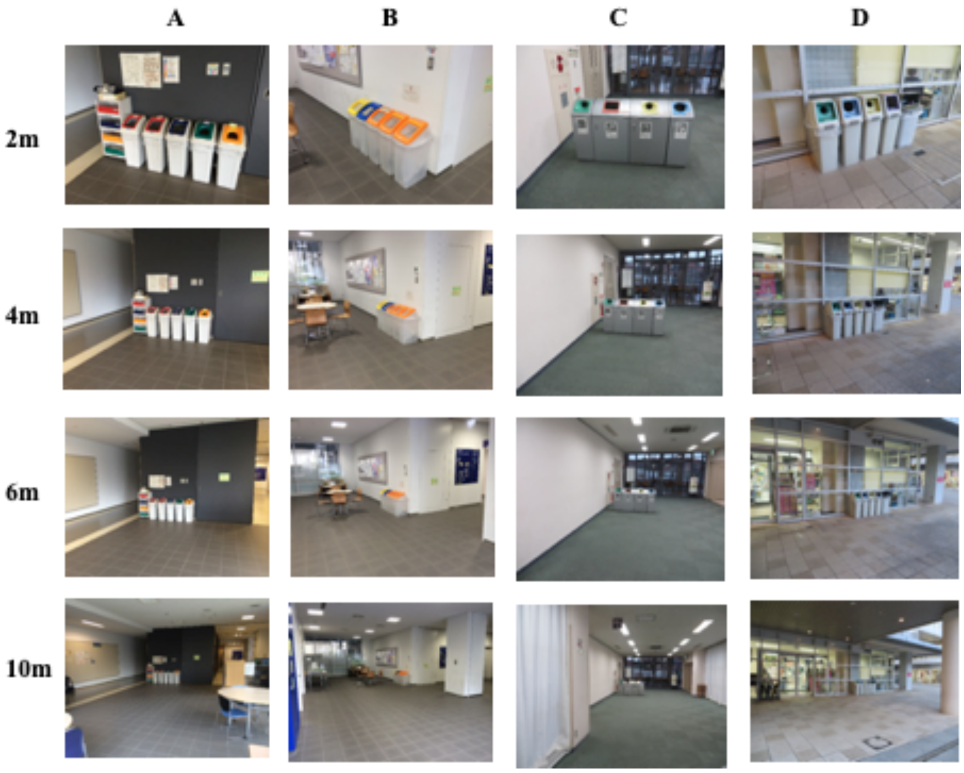


Figure 4–1. Photos of recycling bin with different distance (2m,4m,6m,10m) view

Table 4–1. Seven reference actions used in web-questionnaire for botheration quantified

	Reference action	Adjusted Z value (-)	Market price (JPN yen)
1	Boil water using a kettle (1.5 L)	0.171	4.39
2	Wash two dishes	0.707	25.3
3	Boil two cups of rice using a rice cooker	0.901	343
4	Grill two fishes	1.585	147
5	Cook curry and rice for two persons	1.698	203
6	Cook fried chickens for two persons	1.782	173
7	Fix a flat tire of a bicycle	2.388	1101

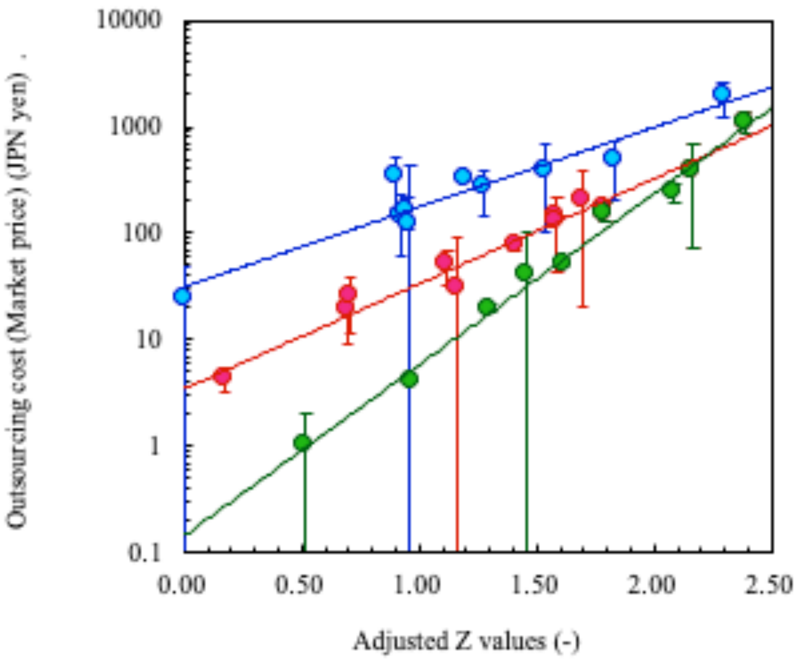


Figure 4–2. Three Single logarithmic linearities between botheration and outsourcing costs of 32 reference actions

4.2.2 Quantified botheration

Figure 4-3 shows the average botheration toward taking wastes to recycling bins with different distances evaluated as Z value and Japanese yen. They are shown in right and left plots, respectively. The left graph shows that Z value is the minimum when the recycling bin with the shortest distance (2 meters). When the distance become the longest (10 meters), the Z value is also the maximum. The Z values in four places show apparently positive linear trends with the distance but different slopes among four places. This means that the perceptive botheration toward bringing wastes to recycling bins becomes stronger with the increase of distance. The same results of botheration can also be verified in the case of Japanese yen (the right graph). The highest "price" is 1.3 yen when bringing wastes 10 meters to the recycling bins at the place C. It is quite lower price compared with the normal daily life cost. It suggests that 10 meters may not be long distance to cause big botheration for people. In addition, in the case of carrying waste 2 meters to the recycling bins, the botheration were always smaller than 0.4 yen at all four places. Therefore, it is considered that people may feel negligible botheration toward bringing wastes when the recycling bin is near enough.

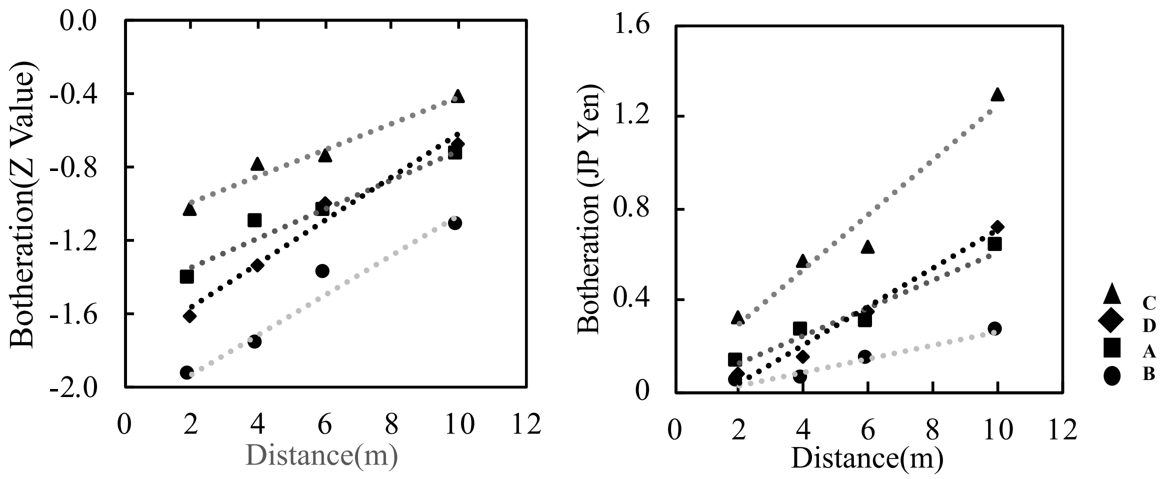


Figure 4–3. Quantified botheration in Z value and Japanese yen of throw waste to recycling bin with different distance at four places respectively

4.3 On-site experiments using recycling bins with different designs

4.3.1 Experiments design on location effect

To investigate the distance impact on waste collection, waste collection experiments were conducted in Suzukakeidai campus of Tokyo Institute of Technology from December 2015 to July 2016. The recycling bins were set in front of the coop-store which is the only convenient store in this campus. The recycling bins were change the setting location (location A, location B, location C) weekly to investigate the distance impact on waste collection performance (see Figure 4-4). The physic distance of each location is the distance between the center of coop entrance to the center of the recycling bin distance of each location is considered. Therefor, the physic distance of each location is 0.80m for A, 3.16m for B and 5.4m for C, respectively.

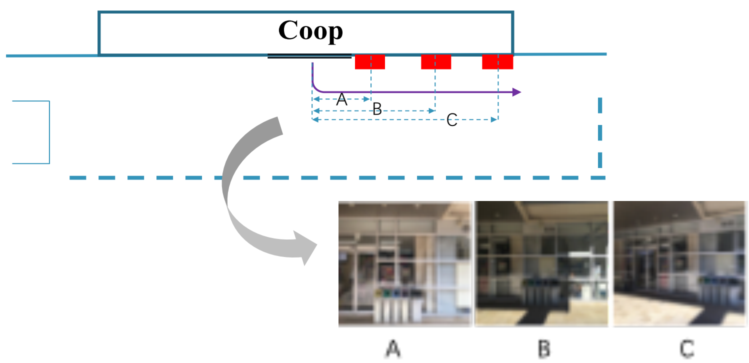


Figure 4–4. The concept of on-site experiments conducted in front of coop store

Potential users of these recycling bins included students, administrators, staff, and visitors at this public university. The wastes collected by combustible waste bin and incombustible waste bin were monitored every day. The recyclable wastes collected by PET bottle bin, can bin, and glass bin were monitored when the bin was about 80% filled. Contaminated wastes were separated from other wastes before waste weight measurements. The weight of total wastes and contaminated wastes were recorded for each recycling bin. In addition, the number of recyclable wastes (PET bottle, can, and glass) were also recorded.

4.3.2 Data analysis on color effect

The recycling bins used in this experiment campaign were combustible waste bin, incombustible waste bin, PET bottle bin, can bin, and glass bin. Body color was gray for all recycling bins. As described in the chapter 2, color preference toward gray is high for all waste types. On the other hand, the colors around insert slot of recycling bins were different. They were purple for combustible waste bin (the worst color preference), gray for incombustible waste bin (the second-best color preference), blue for PET bottle bin (moderate color preference), and green for can bin (moderate color preference) (see Figure 4-5). According to chapter 3, the effect of recycling bin design, in particular coloring around insert slot, on waste segregation, was also included in the analysis.

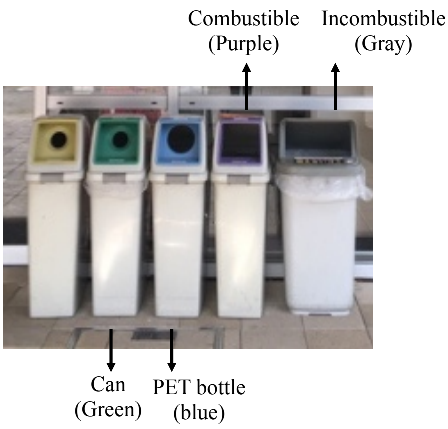


Figure 4–5. Recycling bins with different slot frame color

The correct disposal rate was used to evaluate waste segregation efficiency of each recycling bin. The correct disposal rates of each recycling bin are defined by Eq.2-3, respectively.

$$CDR_i = \frac{W_i}{TW_i} \times 100 \text{ (Eq. 2)}$$

where i is waste type (combustible waste or incombustible waste), CDR_i is correct disposal rate of waste i bin (%), W_i is the weight of waste i collected by waste i bin (kg), TW_i is the total weight of waste i collected by all recycling bins.

$$CDR_j = \frac{N_j}{TN_j} \times 100 \text{ (Eq. 3)}$$

where j is waste type (PET bottle or can), CDR_j is correct disposal rate of waste j bin (%), N_j is the number of waste j collected by waste j bin (-), TN_j is the total number of waste j collected by all recycling bins.

4.4 Results and discussion

4.4.1 Effect of location on waste collection

Figure 4-6 shows the week-average of daily waste collections in left, middle and right locations during 8 months monitoring (combustible and incombustible wastes). Figure 4-7 shows the week-average of daily collection of PET bottle, glass bottle and can in left, middle and right locations in the same period. 1 to 8 of x axis represent the period from Dec 2016 to July 2017.

When the weather become warmer, the total amount of collected wastes have been increased. In the last 3 months, May, June and July, the amount of collected wastes shows significant increase compared with the first three months. Similar results were also found in other countries. Rhyner (1992) researched monthly quantities of residential, commercial, industrial and other wastes generated in the period of 1985–1989 in Brown County, Wisconsin, USA. It was discovered that the monthly quantities of residential and commercial wastes were lower than the average in winter season (up to 19.8%) and higher than the average (up to 23.8%) in summer season. Gidarakos et al. (2006) reported the increase of solid waste generation during the summer season in the island of Crete. Gómez et al. (2009) found the waste generation in January (low temperature season) were 28% lower than that in April in the city of Chihuahua, Mexico.

For collected combustible wastes, the left location recorded the largest daily collection in a week 6 times. It means 75% of the largest daily collection records (in total 8 times). For collected incombustible wastes, the right location recorded 7 times of the largest daily collection in a week. Therefore, the highest collectability of wastes among three locations is the left for both combustible and incombustible wastes. In case of PET bottle, glass bottle and can, the highest waste collectability among three locations are left or middle for PET bottle, middle or right for glass bottle, and middle for can, respectively. However, it should be noted that no statistically significant difference was found in terms of waste collection among these locations.

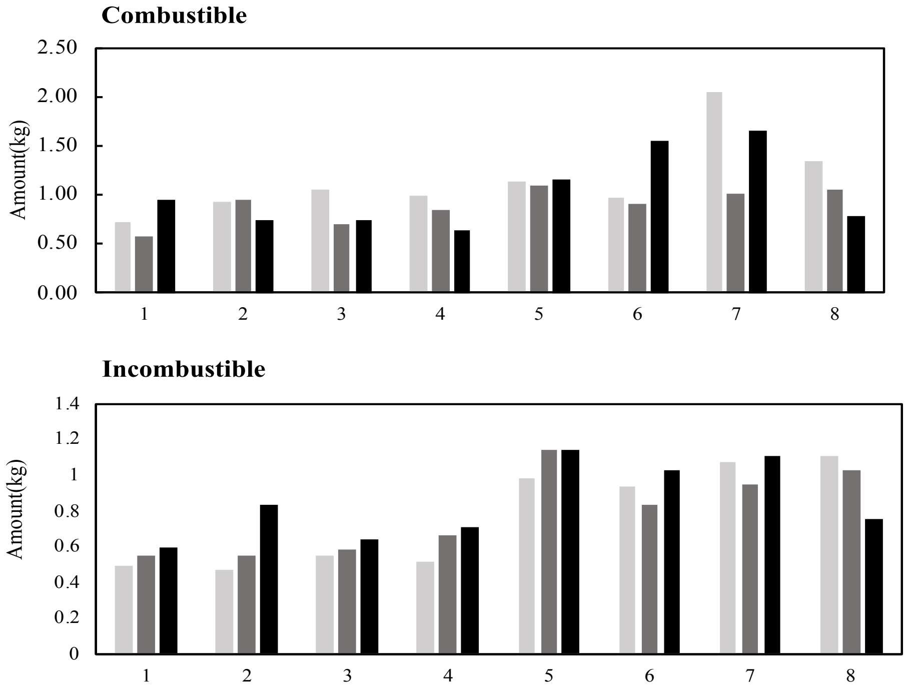


Figure 4–4. Daily amount per week of collected combustible and incombustible waste

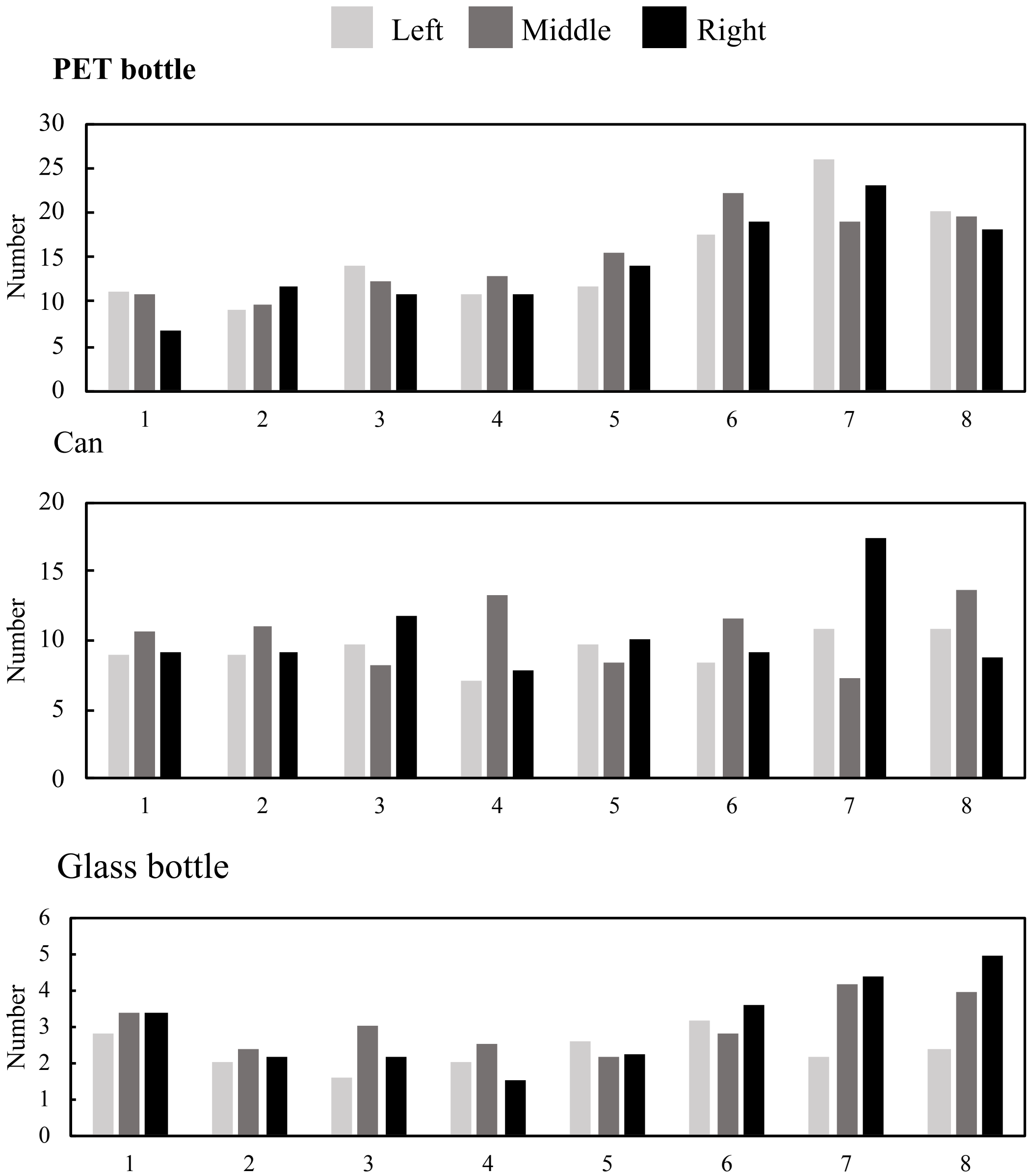


Figure 4–5. Daily number per week of collected PET bottles, glass bottles and cans

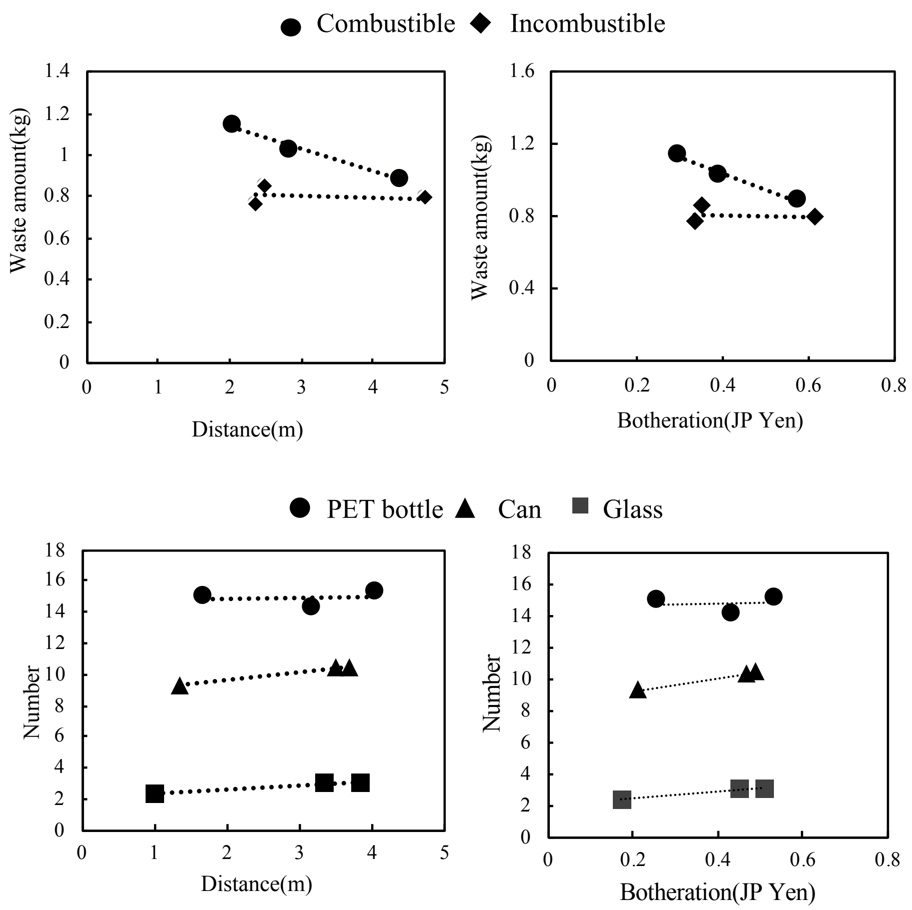


Figure 4–6. The comparisons between collected waste amount with physical distance and quantified botheration

To investigate the distance impact on waste collection, the distance from the entrance of coop store to recycling bins were considered. The left graphs of Figure 4-8 show comparisons between the distance to recycling bins and the amount of collected wastes. The distance was transformed to perceptive botheration toward taking wastes to recycling bin using the linear correlation shown in Figure 4-3 (place D). The right graphs of Figure 4-8 show the relation between perceptive botheration toward taking wastes to recycling bins and the amount of collected wastes. Although it was expected that the amount and the number of collected wastes would decrease with increase of botheration. However, only combustible wastes have clearly negative slope with increase of botheration. On the other hand, the amount of collected incombustible wastes and the number of PET bottle, can, and glass showed no significant trend with the botheration. This might be explained by the difference of physical distances tested in this on-site experiment seems to be too small to generate non-negligible botheration change. When the distance to recycling bins are along with walking path, 8 meters or shower distance gave on impact on waste collection (Leeabai et al., 2019). The results of this study agree with it. The three locations tested in this study were probably along major walking path to the coop store for major buildings in Suzukakedai campus (see Figure 4-9).

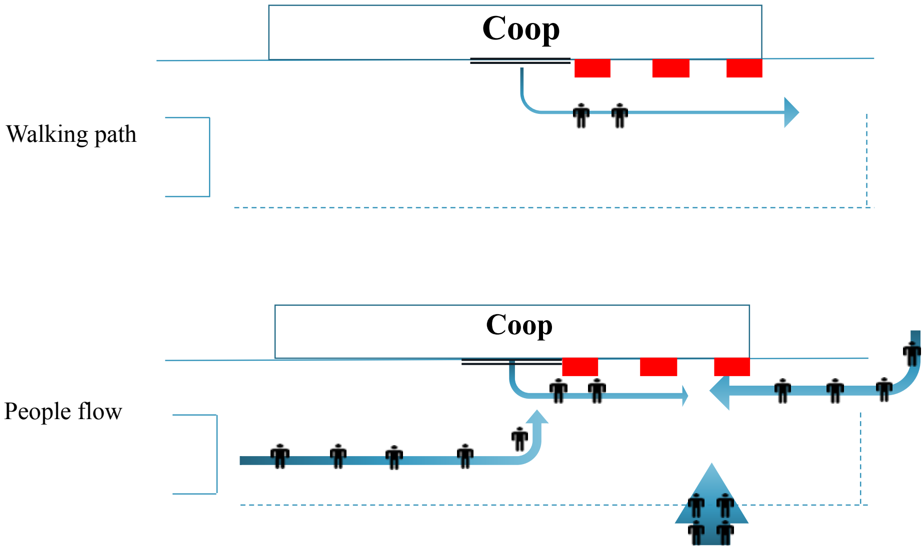


Figure 4–7. The environment of waste collection experiment

4.4.2 Effect of coloring on waste segregation

Correct disposal rates measured in the on-site experiment are shown in Figure 4-10. According to the proposed hypothesis, "impressive color" of combustible waste bin and incombustible waste bin, which are color around insert slot, are the worst preferred and the second preferred. Therefore, correct disposal rates were expected to be low for combustible wastes and high for incombustible wastes, respectively. According to high color preference toward body color ("impressive color" for PET bottle bin and can bin), correct disposal rates of these wastes were expected to be high. The results are partially inconsistent with the expectation. Correct disposal rate of combustible waste is higher than that of incombustible waste. On the other hand, as is expected, correct disposal rates of PET bottle and can are high and similar with each other. Larger size of insert slot of incombustible waste bin might has caused lower correct disposal rate than combustible waste bin. Although signage can influence waste sorting performance (Wu et al., 2018), the impact of "impressive color" on waste segregation, in particular for combustible and incombustible wastes, might be small compared with other design effects.

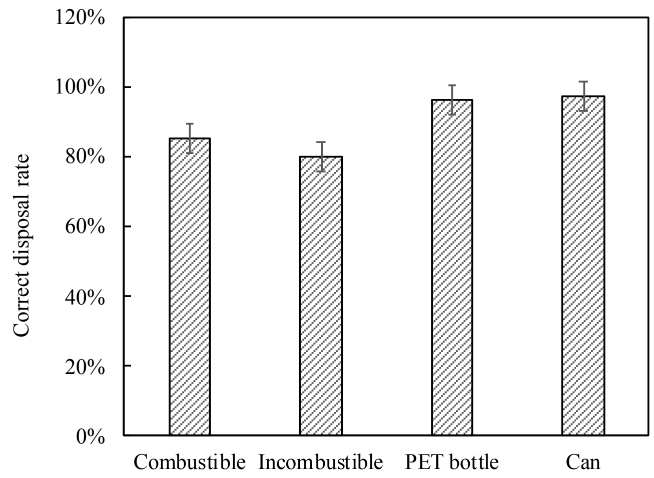


Figure 4–8. Correct disposal rates of combustible waste, incombustible waste, PET bottle, and can (Error bar means standard deviation)

4.5 Conclusion

The results from web-questionnaires suggest the botheration of bring waste to the recycling bin will increase with physical distance, the results from the on-site experiments didn't show significant difference of collected waste with the botheration. The small difference between physical distances may generate non-negligible botheration change. In addition, the setting location on the walking path can eliminate the botheration. in addition, the effect of only impressive color (color used in insert slot) was too weak to improve waste separation. To encourage waste sorting using designed recycling bins, combination of modified design items is necessary.

Chapter 5 Design effect of PET bottle bins on PET bottle collection performance

5.1 Introduction

This chapter focuses on a recycling bin for PET bottles. For high efficiency of PET bottle collection and other waste segregation, following four actions are recommended. They are cap removal, label ripping (removal), bottle washing, and bottle compacting. However, the quality of collected PET bottles is usually bad because foreign materials like other plastic bottles, cans and glasses are always mixed with PET bottles. Sorting process is always necessary before PET bottle recycles. In addition, some PET bottles are still capped when they are collected. It makes difficult to compress PET bottles by collection trucks with compressors and decreases collection/transportation efficiency. Therefore, cap removal and less recycling contamination (less foreign waste mixture) before PET bottle collection are important for efficient PET bottle recycles. In this chapter, 10 different designs of recycling bins for PET bottle was tested in order to explore design preference toward PET bottle recycling bins and its effect on collection performance of PET bottles. In this study, I focused on cap removal from bottles and recycling contamination ratio.

5.2 Method

In this section, design concept of recycling bin is described firstly. Quantification method of perceptive preference toward recycling bin designs and insert slot shapes using web-questionnaire is followed. It aims to investigate connections between perceptive preferences and human behaviors (cap removal and recycling contamination). Finally, on-site experiments of PET bottle collection performances using designed recycling bins and statistical test of monitoring data are described. It aims to investigate the impacts of each design item on human behaviors.

5.2.1 Recycling bin design

In this research, we focused on four design items to design PET bottle bin.

1) The first is single or multi tasks of a recycling bin. In case of single task, individual recycling bin was designed only for bottles or caps. Two recycling bins were used to collect bottles and caps separately. All-in-one type was also designed to collect both bottles and caps by only one recycling bin. It has two insert slots for bottles and caps, respectively. This design item aims to investigate which design can give people a stronger notice of cap removal request.

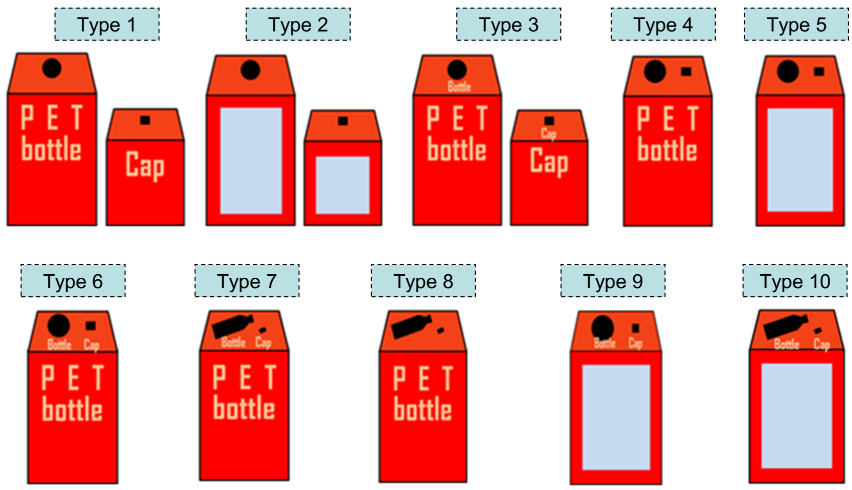
2) The second design item is inside-visibility. The front of a recycling bin is see-through so that people can see bottles, caps, and other wastes inside recycling bins. It might notice people cap removal request and let them easily recognize recycling bins for PET bottles/caps, not other wastes.

3) The third design item is signage like “Bottle” and “Cap”. They are shown near insert slots. Wording notice might be more instructive to deliver cap removal request than visual design of recycling bins.

4) The last design item is insert slot shape. Round and bottle-like shapes were tested in this study. The shape might be more illustrative than wording notice.

Ten designed recycling bins are illustrated in Figure 5-1a. Featuring design items in each designed recycling bin are summarized in Figure 5-1b.

a



b

Type	Separated bin	Inside visibility	Signage	Insert slot shape
1	○			
2	○	○		
3	○		○	
4				
5		○		
6			○	
7			○	○
8				○
9		○	○	
10		○	○	○

Figure 5–1. 10 types of recycling bins designed for investigating the visual effect: (a) illustration of 10 recycling bins, (b) Featuring points in 10 recycling bin designs

Figure 5–2. Six different disposal slot shapes for PET bottle container

5.2.2 Web-Questionnaire

Perceptive preferences of designed PET bottle bins (type 1-6) were measured by binary pairwise comparison method using web questionnaire. In this study, six different shapes were designed for insert slot and tested without showing the whole recycling bin (see Figure 5-2). Tested shapes are round, eclipse, rectangle, diamond, square, and bottle-like shape. Web questionnaires for perceptive preferences of recycling bin designs and insert slot shapes were conducted in Dec. in 2012 and to Oct to Dec. in 2014, respectively (Quickmill®, Macromill Co. Japan). In each web questionnaire, answer data of 210 persons were collected. The questionees were adjusted to balance equal gender ratio and equal age distribution with 10-year interval (20's, 30's, 40's, 50's, and 60's). It should be noted that web questionnaires were conducted in Japanese language and respondents were only Japanese citizens. In addition, there should be a large age gap between the web questionnaires and on-site experiments in Suzukakedai campus of Tokyo Tech. In the on-site experiments, major participants were undergraduate and graduate students with the age less than 30.

5.2.3 PET bottle collection experiments using designed recycling bins

Ten types of designed recycling bins for PET bottles were made using hardboard and set in Suzukakedai campus of Tokyo Institute of Technology in Yokohama city, Japan. They were colored by red spraying to let them look like usual recycling bins made of plastics or metals. However, it should be noted that they might still have looked strange bins and affected participants' recognition and their behaviors. This limitation should be taken into consideration for data analysis and discussions. Participants included the students, University staffs, and visitors to the campus. Designed recycling bins were located alone near PET bottle vending machines or with other recycling bins for combustible wastes, incombustible wastes and cans as shown in Figure 5-3. In the case of "inside-visible" designs (type 2, 5, 9 and 10), some uncapped bottles and some caps were put inside recycling bins before experiments in order to notice participants cap removal request and only PET bottle drop. During experiment campaign, more than

Figure 5–3. Setting condition of recycling bins in this experiment

100 PET bottles were collected by each type of recycling bin excluding the type 10. Collected PET bottles were sorted to capped bottles and uncapped ones. The numbers of PET bottles with/without caps, removed caps, and other wastes were counted and recorded. PET bottles collected by designed recycling bins were monitored once or twice per week.

Using the numbers of bottles with/without caps, removed caps, and recycling contaminations collected by each type of recycling bin, cap removal ratio and recycling contamination ratio were calculated by the equation 2 and 3, respectively.

$$\mathrm{CRR} = \frac{N_{non}}{N_{cap}+N_{non}} * 100\% \text{ (Eq.4)}$$

$$\mathrm{RCR} = \frac{N_{waste}}{N_{cap}+N_{non}} * 100\% \text{ (Eq. 5)}$$

where CRR and RCR are cap removal ratio and recycling contaminations ratio (other waste mixture ratio), respectively. Ncap and Nnon are the numbers of bottles with and without cap, respectively. Nwaste is the number of all wastes, excluding PET bottles, collected by designed PET bottle bins.

In order to evaluate the effect of each design item on cap removal ratio and recycling contamination ratio, three recycling bin designs including the same target design item were grouped for statistical test. For example, in order to investigate the effect of “separated bin” design, a group of type 1, 2, and 3 were compared to the “all-in-one” type group (type 4, 5, and 6). They are shown in Figure 5-4. The differences of cap removal ratio and recycling contamination ratio were tested by one-sided paired t-test with 5% of significance level. When significance differences of cap removal ratio or recycling contamination ratio were accepted by the statistical test, the words “significant” or “significantly” are always described in the text.

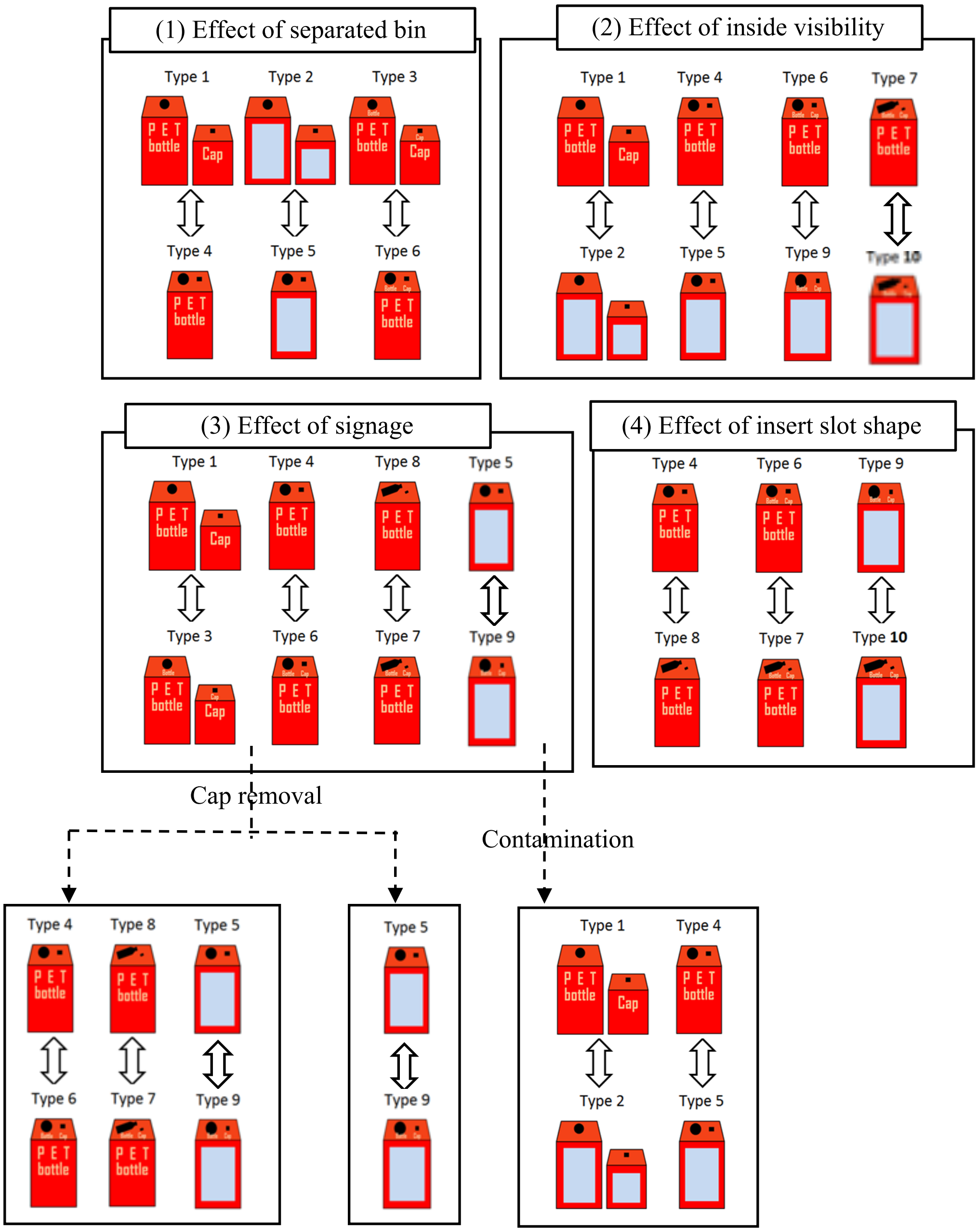


Figure 5–4. Paired comparison to evaluate the effect of recycling bin design on cap removal encouragement and contamination decrease

5.3 Results and discussion

5.3.1 Perceptive preference toward designed PET bottle bins

Six designed PET bottle bins are ordered based on their preference degrees and are illustrated in Figure 5-5a. The preferences toward six recycling bin designs are ordered as type 3 > type 6 > type 1 > type 2 > type 5 > type 4. The most preferred PET bottle bin is type 3. It is two separated and inside-visible bins with signage near the insert slot. The second preferred PET bottle bin is type 6, which is all-in-one type with the signage and invisible front (inside-invisible). Type 1 design, which is separated and inside-invisible bin without signage, has the third highest preference. The worst preferred design is type 4, which is all-in-one and inside-invisible recycling bin without signage. When all-in-one/separated design item is focused on, separated bin designs always have higher preferences than all-in-one designs (type 3 > type 6, type 1 > type 4, and type 2 > type 5). In terms of inside-visible/invisible design item, its effect on design preference is unclear. When recycling bin is separated design (type 1 and 2), inside-invisible design (type 1) is preferred more than inside-visible design (type 2). On the other hand, inside-visible design (type 5) has higher preference than inside-invisible design (type 4) when recycling bins are all-in-one type. Signage ("bottle" and "cap") near the insert slot are effective on design preference. All bin designs with signage (type 3 and 6) have higher preference than the other designs without signage. According to the results of web-questionnaire, it is concluded that signage and separated bin designs increase design preference but inside-visibility is unclear in terms of design preference.

5.3.2 Perceptive preference toward insert slot shapes

The preference degrees of insert slot shapes are illustrated in Figure 5-5b. Bottle-like shape has the highest preference degree. Round shape is second preferred. Square and diamond have the worst preference degrees. The highest preference toward bottle-like shape agrees with the expectation because it is noticeable for bottle disposal. Higher preferences of round and eclipse shapes than square and other box shapes might be explained by cross-section shape of PET bottles (usually round shape). Round or round-like shapes might inspire bottle disposal more than square or square-like shapes. According to the highest preference toward bottle-like shape, three additional designs of recycling bins with insert slot of bottle-like shape (type 7, 8, and 10) were added to the original six designs (type 1-6) for on-site experiments for PET bottle collection as well as type 9 design.

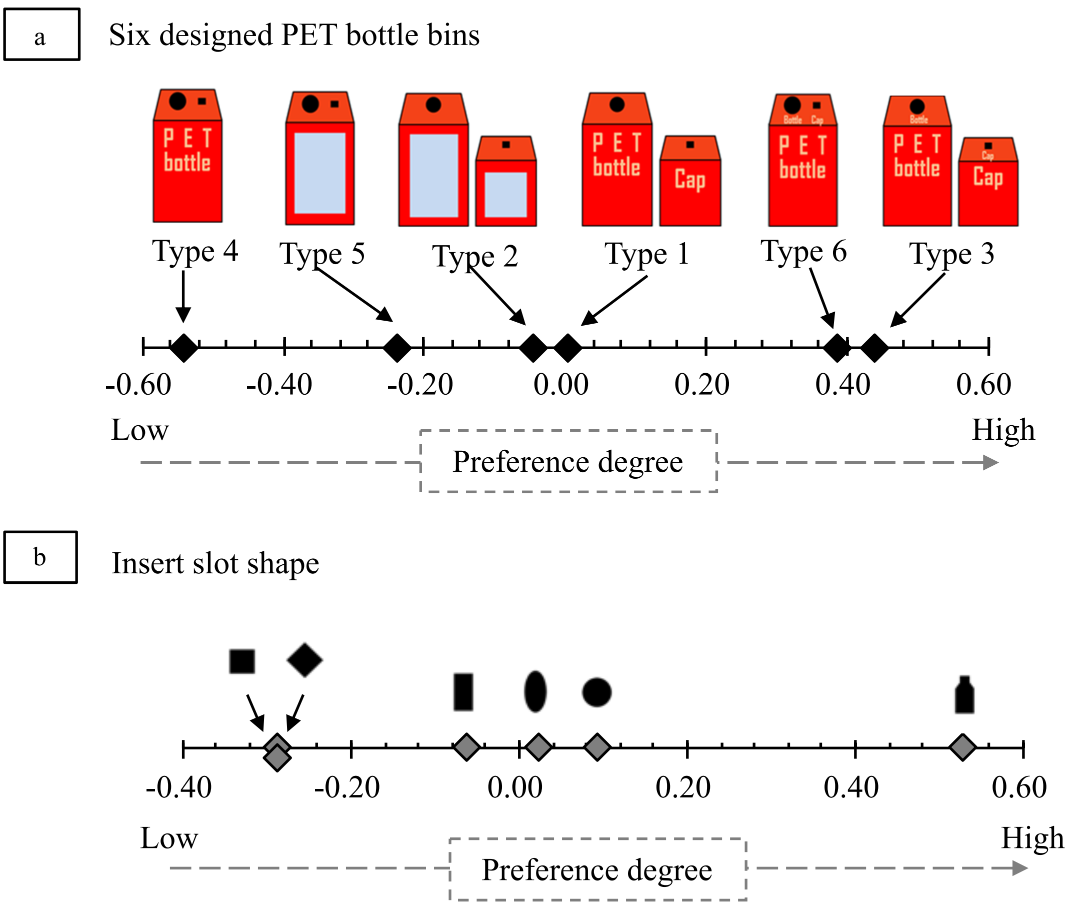


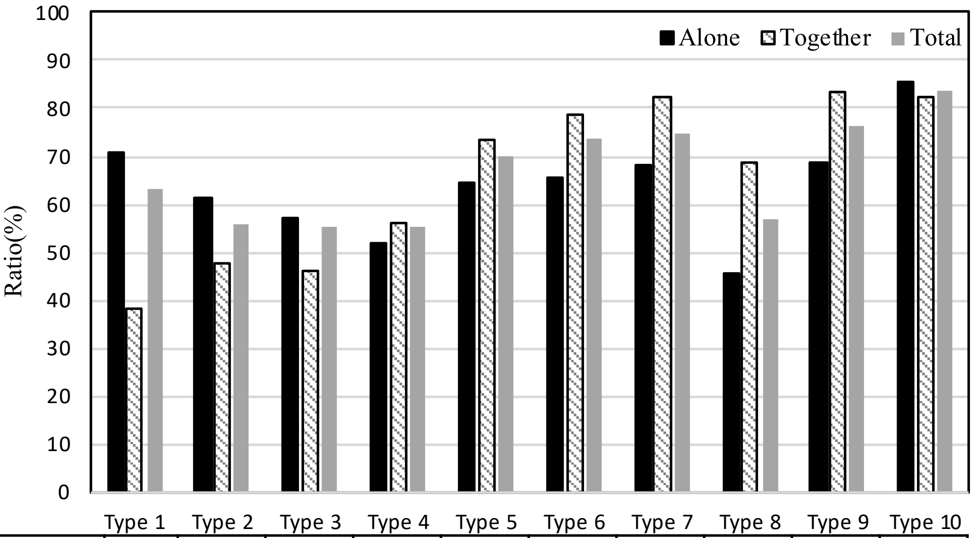
Figure 5–5. Preference degree of tested designs: (a) six designed PET bottle bins (type 1 to 6), (b) the insert slot shape

5.3.3 The effect of recycling bin design on cap removal ratio

All results of collection experiments are summarized in Figure 5-6. To investigate effect of each design item (separated/all-in-one, inside-visible/invisible, signage/no signage near insert slot, and round/bottle-like insert slot) as shown in Figure 5-4, the averages of cap removal ratios and recycling contamination ratios of each design group are shown in Figure 5-7.

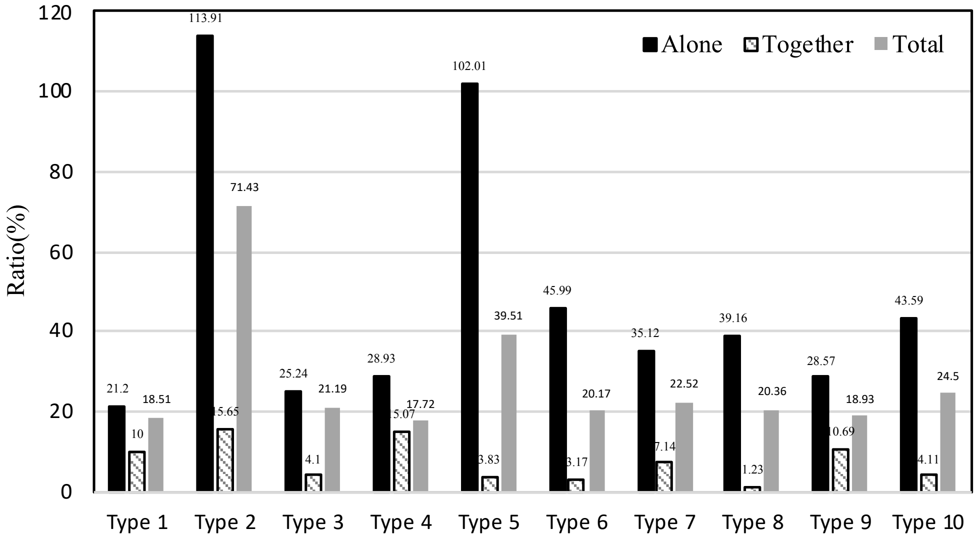
There is large difference between the highest cap removal ratio (85.3 % for type 10) and the lowest one (52.1% for type 4). When the average of cap removal ratios is focused on for each design group shown in Figure 5-7, the all-in-one recycling bin (type 4, 5, and 6) has 9% higher ratio than the separated bin (type 1, 2 and 3). “Inside-visible” recycling bin (type 2, 5, 9, and10) has 5% higher ratio than “inside-invisible” bin (type 1, 4, 6, and 7). The average ratio of the recycling bin with signage near insert slot (type 3, 6, 7, and 9) is 9% higher than that of “no signage” bin (type 1, 4, 8, and 5). Insert slot with bottle-like shape (type 7, 8, and 10) is better than round shape slot (type 4, 6, and 9). However, one-sided paired t-test with 5% of significance level suggests that these differences are not significant. Signage effect on rap removal ratio might be masked by inappropriate designs of recycling bins. Type 1 and 3 designs have large size wording (Cap) in the front. Because caption with larger font size has higher preference than smaller one (Grobelny and Michalski, 2015), they might work as signage primarily and make the small size signage near insert slot negligible in type 3 design. In magazine advertisement analysis, significantly larger attention was received with increase of surface size of text element (Pieters and Wedel, 2004). In fact, type 1 design (no signage near insert slot) has higher cap removal ratio than type 3 (with signage). On the other hand, other designs with signage near insert slot (type 6, 7, and 9) always have higher removal ratios than their counter designs (no signage: type 4, 8, and 5). When type 1 and 3 are excluded from signage comparison group shown in Figure 5-4, significant differences of cap removal ratios between recycling bins with signage and no signage were regarded (p=0.0328). Therefore, this study suggests no clear effect of recycling bin designs excluding signage on cap removal. However, it should be noted that experimental data in this study might be too small to identify design effect beyond experimental biases/errors.

a Ratio of cap removal



	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9	Type 10
Alone	70.89	61.59	57.28	52.07	64.43	65.78	68.29	45.78	68.75	85.26
Together	38	47.83	45.9	55.97	73.18	78.87	82.14	68.71	83.21	82.19
Total	62.98	55.64	55.1	55.22	70	73.67	74.53	57.14	76.54	83.77

b Ratio of recycling contamination



	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9	Type 10
Alone	21.2	113.91	25.24	28.93	102.01	45.99	35.12	39.16	28.57	43.59
Together	10	15.65	4.1	15.07	3.83	3.17	7.14	1.23	10.69	4.11
Total	18.51	71.43	21.19	17.72	39.51	20.17	22.52	20.36	18.93	24.5

Figure 5–6. (a) Ratio of cap removal, (b) ratio of recycling contamination of 10 designed PET bottle bins

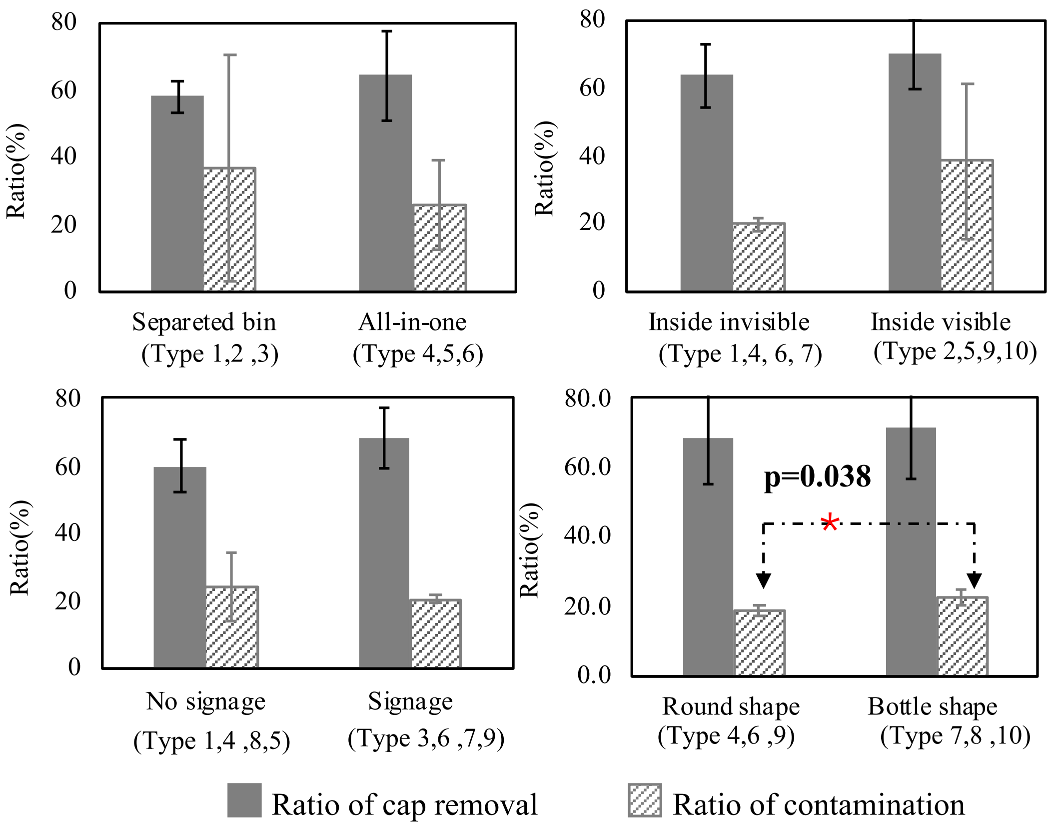


Figure 5–7. Comparison of design effects (4 design items) on cap removal and recycling contamination (the average ratio)
Note: Error bar is 95% confidence interval

5.3.4 The effect of recycling bin design on the ratio of recycling contaminations

Experimental results of recycling contaminations for all designed bins are summarized in Figure 5-6 and 5-7. As shown in Figure 5-6 and 5-7, type 2 design, which is inside-visible with round insert slot and no signage, had greatly higher ratio of recycling contaminations than other types. The other "inside-visible" recycling bin (type 5) has the second highest recycling contamination ratio. On the other hand, type 9 design had almost equal ratio with counter-design bin (inside-invisible; type 6) although it is also inside-visible design. This difference might be contributed by signage and/or accidental events. Type 2 and 5 designs have no signage but type 9 design has signage near insert slot. Signage might have contributed to low recycling contamination for type 9 design. Type 10 design, which is also inside-visible and has signage near inset slot, had comparative recycling contamination ratio with other designs excluding type 2 and 5. It also supports signage contribution to low recycling contamination. It would be discussed again in this section. Accidental events should be also considered. If other waste is dropped incorrectly to the inside-visible recycling bin, they might discourage people from waste separation and correct disposal. When this cycle starts, recycling contaminations will be accelerated and let people less conscious to waste separation. Berger and Hevenstone also report that the signs of disorder; a littered condition of recycling bin might weaken norm maintenance and increase scattered waste disposal (Berger and Hevenstone 2016). This negative cycle might have happened at the early stage of PET bottle collection experiments using type 2 and 5 design bins but not happened in the experiment using type 9 and 10 recycling bins. If this mechanism really occurs, design effect of separated/all-in-one bins on recycling contamination ratio should be carefully evaluated. Figure 5-7 shows that the average ratio of recycling contaminations of separated bin group (type 1, 2, and 3) is clearly higher than that of all-in-one bin group (type 4, 5, and 6). However, this difference is not regarded as significant by the paired t-test. When data of type 2 design and its counter-design (type 5) are excluded, average ratios of recycling contaminations are comparable (19.9 % for separated bin design and 18.9 % for all-in-one design). Therefore, it can be concluded that the effect of separated/all-in-one bin design is negligible on recycling contamination ratio. Owing to higher preferences of recycling bin designs with signage shown in Figure 5-5a (type 3 and 6) and lower contamination ratios of type 9 and 10 designs (inside-visible with signage) than those of type 2 and 5 (inside-visible without signage), significant effect of signage on recycling contaminations were expected. However, the paired t-test suggests no significant effect ($p=0.302$). It is inconsistent with previous researches reporting that encouraging/motivational signs could be simple and low-cost method to enhance recycling (Verdonk, et al.,2017; Becker et al.,2014). As described in section 3.3, large size wording (PET bottle) in the front for type 1, 3, 4, 7, and 8 design bins might have worked as primary signage and masked the effect of signage near insert slot. When only type 5 and 9 designs (inside-visible and no large size wording in the front) are compared, recycling bin with signage near insert slot (type 9) has much lower contamination ratio than the bin without signage (type 5) (see Figure 5-6b). In addition, when type 1 and 4 design bins (large size wording "PET bottle" in the front) are compared to type 2 and 5 (no word in the front owing to see-through window), the average of contamination ratio of the former group (=18.1%) is greatly lower than that of the latter group (=55.5%). Although this study partially supports signage contribution to lower contamination, it failed to verify significant effect of signage on waste contamination statistically owing to inappropriate designs.

Insert slot shape is effective on recycling contamination ratio ($p=0.038$). Round shape designs (type 4, 6, and 9) generated significantly lower ratios of recycling contaminations than bottle-like shape designs (type 7, 8, and 10). Because bottle-like insert slot has greatly higher preference degree than round insert slot (see Figure 5-5b), this result is contradictory to perceptive preferences of round insert slot and bottle-like insert slot. It might be possible to explain the gap between perceptive preference toward insert slot shape and waste separation behavior using the Theory of Planned Behaviour (Ajzen, 1991). Xu et al included “perceived moral obligation” and “past experience” to extend this psychological model (Xu et al., 2017). In household waste separation behaviors of Hangzhou residents in China, past experience contributed to “behavior” as much as “intention”. On the other hand, “attitude” has no impact on intention. Round shape is common for conventional recycling bins for PET bottles and cans in Japan. Therefore, Japanese citizen should have rich experiences that they dropped PET bottles to a recycling bin with round insert slot. Perceptive preference toward insert slot shape can be included in attitude. In this sense, the result in this study agrees with the structural model proposed by Xu et al. However, it should be noted that contributions of model variables to “behavior” depend on cultural context, social pressure, and others (Klöckner, 2013, Oreg and Katz-Gerro, 2006, Stoeva and Alriksson, 2017). Further study is still necessary to verify significant effect of insert slot shape on recycling contamination.

5.3.5 The combined effect of setting condition and recycling bin design on PET bottle collection

5.3.5.1 The effect of recycling bin setting condition on PET bottle collection

In order to carefully analyze design effect of recycling bins, the authors focused on setting condition of recycling bins. As described in the previous section 2.3.1, a PET bottle bin was set alone or together with other recycling bins for combustible wastes, incombustible wastes, and others in this experimental campaign (see Figure 5-3). All data of cap removal ratio and recycling contamination ratio were separated by the setting condition (“alone” or “together”). Separated results are summarized in Figure 5-6. The paired t-test using all data of type 1 to 10 designs suggests that “together” setting gave no significant impact on cap removal ratio ($p=0.387$) but significantly decreased recycling contamination ($p=0.0015$). This finding is similar to previous researches (Andrews et al. 2013, Heathcote et al., 2010). Waste separation was promoted with the increase of recycling bin combination. In the previous section 3.4, it is proposed that incorrectly disposed wastes might have promoted recycling contaminations for “inside-visible” design bins. Figure 5-6b and the statistical test suggest that this “waste-invite-waste” mechanism can be inhibited when a PET bottle bin was set together with other recycling bins. Even if recycling contaminations accidentally happens, "together" setting of recycling bins might guide people to drop their wastes correctly.

5.3.5.2 The combined effect of setting condition and design item on cap removal

The averages of cap removal ratio under each setting condition are shown in Figure 5-8. When a PET bottle bin was set alone, no significant difference was found for each design item (separated/all-in-one, inside-visible/invisible, with/without signage near insert slot, and round/bottle-like insert slot) in terms of cap removal ratio. As described in section 3.3, however, type 1 and 3 should be excluded in the statistical test of signage effect owing to large size wording (Cap) in the front of recycling bins. When they are excluded, significant difference of cap removal ratio was still not detected but its p value got close to significance level ($p=0.062$). On the other hand, significant differences caused by design items were found in the case of "together" setting. Signages are effective to increase cap removal ratio ($p=0.013$). In addition, all-in-one design bins also have significantly higher average ratio of cap removal than separated design bins ($p=0.014$). It is contrast to design preference measured by the web questionnaire (see Figure 5-5a). Although separated design was preferred more than all-in-one design, all-in-one design produces higher cap removal ratio than separated bin design. Because a small recycling bin for caps was smaller than other recycling bins, "together" setting might let the cap bin less noticeable. It is supported partially by the results that all separated design bins (Type 1, 2, and 3) had lower cap removal ratios than all of other design bins (see Figure 5-6a) when together setting. All-in-one designs required a shorter action to drop a cap into the insert slot than separated designs. It might also have contributed to this difference. Kalatzi et al. also reported that shorter action was preferred to drop a waste. People chose the nearest recycling bins from the place a plastic bottle was found (Kalatzi et al., 2015). On the other hand, when separated design bins were set alone, the smaller recycling bin for caps is noticeable. Its contribution to cap removal might be comparable to shorter action requirement of all-in-one design bins for cap drop.

5.3.5.3 The combined effect of setting condition and design item on recycling contamination

No significant design effect was found on recycling contamination ratio under both two setting conditions. The effect of signage on recycling contamination and its dependency to setting condition needs careful discussion. When only type 5 and 9 designs (inside-visible and no large size wording in the front of the bin) are compared, recycling bin with signage near insert slot (type 9) has 72% lower contamination ratio than the bin without signage (type 5) under "alone" setting condition. Signage contribution to lower recycling contamination is consistent to previous researches (Verdonk, et al.,2017; Becker et al.,2014). On the other hand, the recycling bin with signage (type 9) has 1.8 times higher contamination ratio than the bin without signage (type 5) under "together" setting condition. These contrast results suggest that signage effect on recycling contamination might be decreased when recycling bins are set with other bins. As described in section 3.4, recycling bins with large size wording in the front (type 1 and 4) are compared to those with no-wording bins (type 2 and 5) when wording in the front is considered as primary signage. Under "alone" setting condition, the average of contamination ratio of wording bins (=25.1%) is greatly lower than that of no-wording bins (=108%). The paired t-test also suggests significant difference between wording bins (type 1 and 4) and no-wording bins (type 2 and 5) (p=0.038). On the other hand, the difference becomes less than 3% points under alone setting condition. They are 12.5% for wording bins and 9.74% for no-wording bins, respectively. The dependency of signage effect to setting condition might be explained by its noticeability. When several recycling bins are set, wording in the front of the bin receives less attention and thus gives less effect on recycling contamination. It is proposed that object-based attention decreases with increase of object set (Janiszewski, 1998, Perschel and Orquin, 2013). Because the number of objects in a scene create visual clutter or visual crowding, it inhibits the identification of target object (Levi, 2008, Rosenholtz et al., 2007, Whitney and Levi, 2011). In "together" setting, graphical signage is recommended rather than wording. Wu et al reported that graphical signage was better than wording in terms of waste sorting performance (Wu et al., 2018).

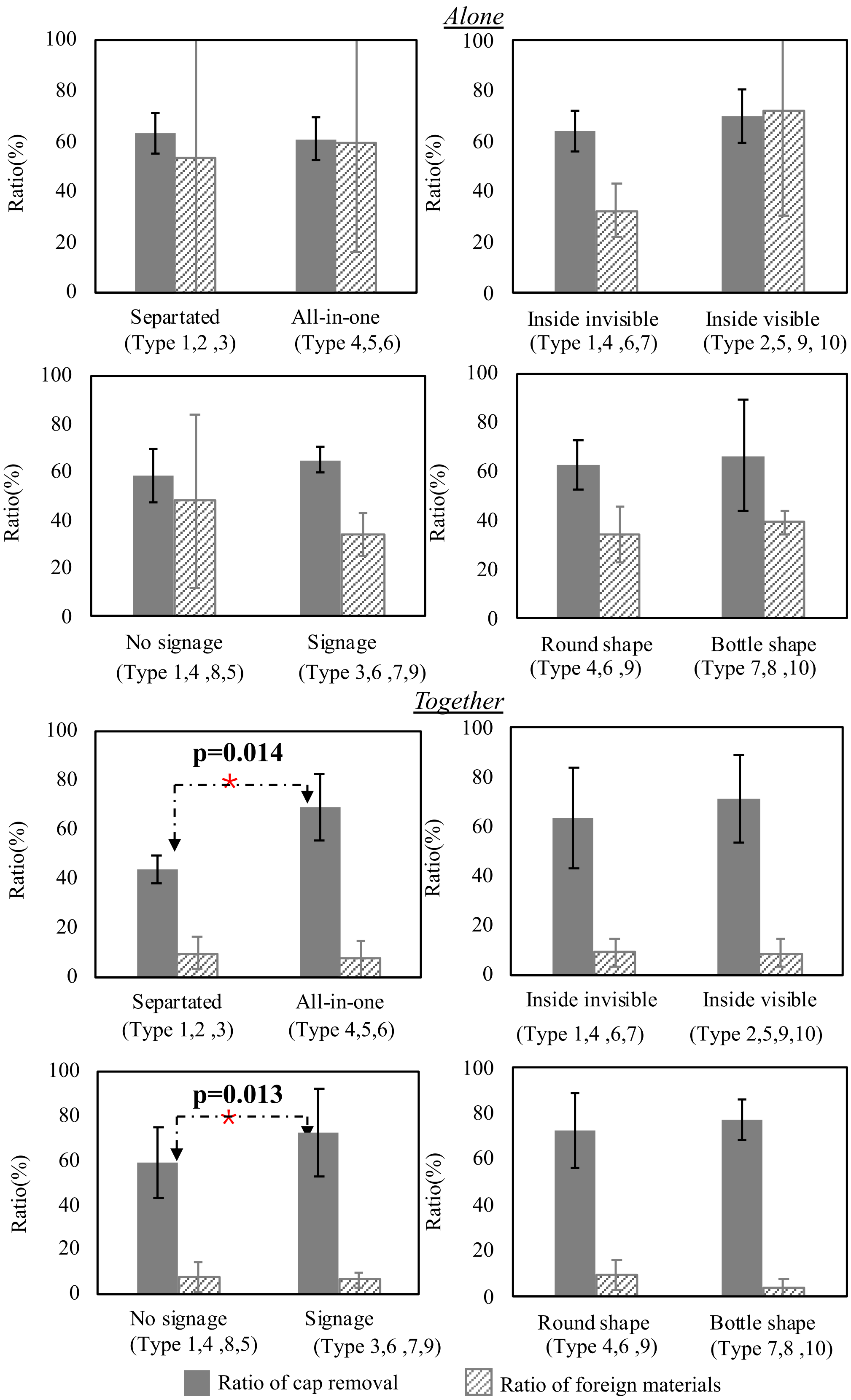


Figure 5–8. Comparison of design effects (4 design items) on cap removal and recycling contamination (the average ratio in two setting conditions).
Note: Error bar is 95% confidence interval

5.4 Limitations of this study and recommendations for further study

Limitations of this study is small diversity of persons involved in on-site experiments. The most of recycling bin users were University students and staffs in Tokyo Tech. They were young, highly educated, biased to male majority, and might have stronger consciousness on waste recycling than general people. Because these properties can give some impacts on waste separation performances (Liere and Dunlap,1980; Samdahl and Robertson,1989), the collected data might be biased compared to experiments in public spaces. It might also have caused the non-negligible gaps between perceptive preference toward recycling bin designs and PET bottle collection performances to some extent. This study found that it was difficult to explain human behaviors (cap removal and waste separation) using only perceptive preferences of recycling bins. An approach using expanded models in the Theory of Planned Behavior might be promising to quantitatively evaluate contributions of design preferences to waste separation behaviors in psychological processes (Conner and Armitage,1998; Xu et al., 2017; Stoeva and Alriksson,2017). On the other hand, this study also found that the design effect on cap removal and waste separation had dependency to setting condition of recycling bins. It might be explained by the noticeability of design items. The theory of competition of attention, proposed by Janiszewski (1998) and modified by Perschel and Orquin (2013), might be useful to verify the attention to design items, in particular wording/signage, quantitatively. In terms of rational designing of recycling bins, not only psychological approaches but also sensing/monitoring technology-based approaches might be taken into consideration. Sensorized recycling bins are effective for routing optimization of collection trucks (Rovetta et al., 2009; Wen et al., 2018). Appropriate design for accurate sensing of recycling bins is also a promising approach.

5.4 Conclusion

This chapter investigated the effect of PET bottle bin designs on cap removal and recycling contamination. Although bottle-like shape was more preferred for insert slot than round shape, recycling bin with round insert slot had significantly lower recycling contamination. The distinct gap between perceptive preferences of insert slot shapes and recycling contamination might be explained by past experience. Conventional recycling bins usually have round insert slots and thus might be helpful for people to notice PET bottle disposal. This study found that the effect of recycling bin setting conditions, which were single setting or commingled setting, were larger than those of design effect. Commingled setting decreased recycling contamination significantly but gave no effect on cap removal. In addition, this study found that design effect depended on setting condition of recycling bin. When the PET bottle bin was set together with other recycling bins, signage and all-in-one design significantly promoted cap removal action. Lower recycling contamination of all-in-one design bins is contrast to higher perceptive preference toward separated design. An approach using psychological models in the Theory of Planned Behavior might be useful to explain the gap between perceptive preference toward recycling bin designs and waste separation behavior (Ajzen, 1991; Stoeva and Alriksson, 2017; Xu et al., 2017). On the other hand, signage gave no significant effect on recycling contamination under "together" setting condition. However, it gave significant effect on recycling contamination under "alone" setting when large size wording in the front of recycling bins is considered as signage. Inside-visible design gave no significant effect on both cap removal and recycling contamination regardless of setting condition. The dependency of design items to setting condition of recycling bins might be explained successfully using Theory of Competition of Attention (Janiszewski, 1998; Perschel and Orquin, 2013). To improve waste collection performance by appropriate design of recycling bins, this study concludes that further psychological approaches are necessary for rational designing.

Chapter 6 Design effect of recycling bins on firework events

6.1 Introduction

The waste generation is usually higher in summer sthan winter (Rhyner ,1992; Gidarakos et al. 2006; Gómez et al. 2009). In Japan, various social events are conducted in summer season. In these events, foods and drinks are usually sold inside and/or near event location. These summer events are one of main reason for high waste generation in summer (Zeng et al. 2005). Regardless of seasonality, public events and festivals will generate a tremendous amount of waste when the events involve food and drink (Gibson and Wong, 2011; Laing and Frost, 2010). The wastes include combustible wastes, incombustible wastes, and a lot of drink containers like PET bottle, cans, and glasses. Therefore, it is necessary to install temporary recycling bins for waste collection and waste separation. To maximize the effectiveness of waste collection using recycling bins, appropriate design/installation (setting) of the recycling bins in public events are recommended. On the other hand, even the Japanese people are already acquainted with waste separation and resource recycling rules, their behaviors can be changed under crowded conditions. The recycling bin installation in the public events might give different design impact on waste collection and separation.

In this chapter, the recycling bin management on firework events were investigated. From the prior chapters, the design preference and design effect of recycling bins used in the society and university campus are discussed. The features of suitable recycling bins used in firework events will be different. The design features and impact of recycling bins will be discussed through the comparisons among various recycling bin installation in different firework events.

6.2 Methods

In the summer seasons in 2015 and 2018, filed surveys were conducted. In 2015, six annual firework events held in Kanto region were chosen to investigate the management of recycling bins. In 2018, three fireworks were additionally selected to investigate recycling bin management further.

The firework events were selected focusing on event scale. They were the number of fireworks and the number of participants. In the six firework events, three events were in Tokyo and the other three were in the other cities. Table 6-1 shows the details of firework events in nine different places. According to the numbers of fireworks and participants, monitored events were categorized into three types: large scale, middle scale, and small scale. The nine firework events were sorted by the number of participants as the first priority and the number of fireworks as the second priority.

Large scale: Sumitakawa firework event and Edokawa firework event in 2015, Adachi and Edokawa frework events in 2018. The number of participants was around 900000 and the number of fireworks was over 10000.

Middle scale: Kotoku firework events and Kanazawa firework events in 2015, Kamakura firewok events in 2018. The number of participants was around 300000 and the number of fireworks was around 3500.

Small scale: Kawagoe firework events and Numata firework events. The number of participants was less than 100000 and the number of fireworks is around 10000.

The size and the number of recycling bins were recorded in each event. The situations of recycling bins before and after events were recorded by photos for waste collection monitoring.

Table 6–1. The situation of firework events in total 9 different places.

Year	2015						2018		
Firework place	Sumitakawa	Edokawa	Edouku	Kanazawa	Kawagoe	Numata	Adachi	Edokawa	Kamakura
Number of Participants	950000	900000	350000	280000	90000	47000	660000	900000	150000
Number of fire works	20000	14000	4000	3500	8000	10000	13600	14000	4000

6.3 Results and discussion

6.3.1 The design of recycling bins

Unlike the existing recycling bins discussed in the previous chapters, the design of the recycling bins for firework events are simple: single color and no special design. Figure 6-1 shows the recycling bins in the nine fireworks events. The temporary recycling bins are all made of recyclable materials. The recycling bins in Sumidagawa and Edogawa are made of cardboard papers. In Koutoku firework event, the organizers used paper carton and plastic box to collect waste. In Kanazawa and Kamakura firework events, recycling bins were made of plank. In Kawagoe, Numata, and Adachi, the recycling bins were made of metal frames. Only in Sumidagawa, the recycling bins for PET bottle, can and glass bottle used circle shape for disposal slots.

The separation rule in each firework events are different. In Japan, each municipality has different separation rule of daily waste. Because the participants may come from the different municipalities, therefore, users can know the separation rule according the types of recycling bins. There are three common waste types in our daily life: combustible, incombustible, and recyclable wastes (PET bottle, can and bin). As listed in Table 6-2, waste separation rules in firework events were basically based on these three types of wastes (combustible, incombustible, recyclable wastes including PET bottle, can and glass). Basically, the waste is separate into combustible waste, incombustible waste, PET bottle, can and glass. From the recycling bins in Sumitakawa and Kanazawa, we know they collect the PET bottle, glass and can in one recycling bin. the users are no need to separate. But in Numata, Adachi, and Kamakura, the PET bottle, can and glass should be put separately in each recycling bins. Sumidagawa and Kanazawa used one container for recyclable wastes. In Koutoku firework event, only two types of recycling bins were used for waste separation (combustibles and incombustible wastes). Cans and glasses were collected using incombustible waste container. Kotoku and Edokawa had no container for PET bottles and no instruction how to dispose of the PET bottles. In Kawagoe firework events, wastes were separated into combustible wastes, cans, glasses, and PET bottles. Numata firework events used complex waste separation method. They set the containers for can, PET bottle, and glass bottle, respectively. In addition, the container for the cap of PET bottles was also used. In this event, a plastic bucket was also installed specifically for collection of remaining drinks.

Table 6-3 shows the size and the number of recycling bins of eight firework events. Kamakura firework event used the largest volume of recycling bins, which was more than twice larger than that of the second one (Kanazawa). Numata firework event used the smallest volume of recycling bins, followed by Kotoku firework event. In terms of bin capacity (volume) per one person, the largest personal bin capacity was Kamakura firework events, followed by Kanazawa event. The personal bin capacity in the Kamakura firework events were over 20 times larger than the smallest personal bin capacity (Kotoku). In addition, although the number of recycling bin locations in Edokawa firework event was about seven times as large as that in Adachi firework event, the total capacity of recycling bin was quite smaller than that in Adachi firework event. In Kanazawa firework events, it used the biggest bin capacity than the other events. The event organizers only set the recycling bins in four locations and total 12 recycling bins. But total volumetric capacity of these recycling bins was still the second largest of nine firework events.

Figure 6–1. Recycling bin in each firework events

Table 6–2. Type of recycling bin in each firework events

Fire work place	Type of recycling bins			
Sumitakawa	Combustible	incombustible	PET bottle, can, glass	
Edokawa	Combustible	incombustible	Can, glass	
Edouku	Combustible	Incombustible, can, glass		
Kanazawa	Combustible	incombustible	PET bottle, can, glass	
Kawagoe	Combustible	incombustible	PET bottle	Can, glass
Numata	Combustible	PET bottle	Can	Glass
Adachi	Combustible	PET bottle	Can	Glass
Kamakura	Combustible	PET bottle	Can	Glass

Table 6–3. The situation of recycling bins in firework events

	Large size			Middle size			Small size	
	Sumitakawa	Edokawa	Adachi	Kotouku	Kananzawa	Kamakura	Kawagoe	Numata
Number of location	8	52	16	19	4	6	14	3
Total volume	34999	22000	171346	8729	73445	74338	20760	5499
Personal volume	0.037	0.024	0.26	0.025	0.262	0.496	0.231	0.117

6.3.2 Waste collection and separation performance

In case of large-scale firework events, all recycling bins were full of waste collection capacity as shown in Figure 6-2. The wastes headed up like waste mountains around the recycling bins. Most of the containers could not be distinguished any more. The containers lost the function of waste separation and all the wastes were mixed together. At the beginning of the event, the situation of waste separation was good. Wastes were disposed of in the correct container (see Figure 6-3). When the firework event proceeded with time, waste collection reached the capacity of small recycling bins and eventually exceeded the capacity. Like the broken window theory, people would not continue to follow the waste separation rule when recycling bins were full. Finally, a lot of people disposed of their waste without any separations. In addition, the accumulated waste makes the recycling bins disappeared, which eventually resulted in littering. The materials used in these recycling bins (paper carton and hardboard) were difficult to recycle because they got dirty by wet wastes. In the first and the second field surveys, Edokawa event used the same recycling bins, and the situations after fireworks was almost the same (waste littering around recycling bins). Sumidagawa event showed totally different results from Edogawa event. The recycling bins were set in small limited area in the event site. Specifically design of disposal slots were not observed. The results of Adachi event were better than Edogawa event because the total capacity of recycling bins was bigger than that in Edogawa. Adachi firework event showed the similar results with Edogawa, but partially different results were also found. Adachi event put the containers along the main road, not on the grassland area where people gathered for watching firework show. Although the containers were not enough for waste collection, the littering situation was rarely found in the Adachi event.

Edokawa

Kawagoe

Figure 6–2. The situation of recycling bins after firework events (Edokawa, Sumitakawa,Adachi)

Edokawa

Sumitakawa

Adachi

Figure 6–3. The situation of waste separation at beginning

In the case of middle-scale fireworks, Koutoku and Kawagoe events showed the same results with Edokawa (see Figure 6-4). On the other hand, the other middle-scale events (Kanazawa and Kamakura) showed better results around recycling bins. Large capacity of containers prevented from overcapacity and made collection service time longer. In addition, large recycling bins were easy to find them. It was also effective to clearly show the location of waste collection in visitors' instruction. The separation way in Kanazawa event was very helpful for visitors. Kanazawa and Kamakura firework events prepared volunteer staffs near recycling bins to help waste separation (see Figure 6-5). Eventually, good waste separations were observed in Kanazawa event. In Kamakura event, the container for recyclable wastes was small but the volunteer staff changed the plastic bag inside recycling bins when they got full.

The two small-scale firework events (Kawagoe and Numata) showed no good result compared with Kanazawa and Kamakura firework events. Because the site area and the number of event participants were smaller than other fireworks events, waste management was expected to be easier than other events. However, contrast results were observed. Poor performances of waste collection in these events seem to be derived from too small capacity of recycling bins. In Numata firework events, waste separation rule might have been too complex under crowded conditions.


Kotouku


Kawagoe

Figure 6–4.The situation of recycling bins after firework events (Kotouku and kawagoe)


Kamakura


Kanazawa

Figure 6–5. The volunteers near the recycling bins (Kamakura, Kanazawa)

6.4 Conclusions

During the firework events, the effect of past experience on human behavior are limited. From the successful experience of Kanazawa and Kamakura firework events, the suitable recycling bins are required to designed with large capacity to manage the large amount of waste generated in a short time. In addition, proper setting location (on the walking pass) based on the surrounding environmental can effective improve the human behavior (waste collection). The volunteer around the recycling bins strongly effect on the waste separation behavior. Based on the theory of planned theory, individual in Japanese culture pay more attention to expectation from significant others in order to maintain good harmony with others (Ando, k., et al, 2010).

Chapter 7 Conclusion

This thesis aims to systematic analysis the trash bin design and the design effect on waste collection and separation.

In **Chapter 2**, preferred color, slot shape, slot position and arrangements of recycling bins are found by pairwise comparison method. The most preferred colors of recycling bins are red for combustible waste, black for incombustible waste, blue for can and white for pet bottles, respectively. The most preferred slot shapes are rectangle for combustible and incombustible, two circles for PET bottle and can, respectively. People preferred combustible waste container on the left side and incombustible waste container in the next position. Recyclable wastes (PET bottle and can) containers on the right side are also preferred. Appropriate design and arrangement of recycling bins might be able to encourage users to separate wastes psychologically.

Chapter 3 found that highly preferred colors were consistent with frequently used colors in slot frame for combustible and incombustible waste bins, and body colors for PET bottle bins. In addition, there was a statistically significant correlation between color preferences and color usage rates. It is proposed that color used in certain item is so impressive that it affects color preference. Design preferences toward different red-colored recycling bins supports this hypothesis. In the case of insert slot shape, good agreements were also found between frequently used slot shapes and highly preferred shapes. Larger and angular shapes were preferred for combustible and incombustible waste bins. On the other hand, rounded shapes were popular for PET bottle/can bins. A significant correlation was also found for insert slot position between position preferences and slot position rates. According to significant correlation between design preferences and design usage rate in real recycling bins, this study proposes that design preference toward recycling bins is affected by past perceptions of recycling bin designs.

The results recommend color using in the slot frame of recycling bins is red for combustible waste, black for incombustible waste, green for PET bottles and blue for can, respectively.

Chapter 4, The results from web-questionnaires suggest the botheration of bring waste to the recycling bin will increase with physical distance, the results from the on-site experiments didn't show significant difference of collected waste with the botheration. The small difference between physical distances may generate non-negligible botheration change. In addition, the setting location on the walking path can eliminate the botheration. in addition, the effect of only impressive color (color used in insert slot) was too weak to improve waste separation. To encourage waste sorting using designed recycling bins, combination of modified design items is necessary

Chapter 5 investigated the effect of PET bottle bin designs on cap removal and recycling contamination. This study found that the effect of recycling bin setting conditions, which were single setting or commingled setting, were larger than those of design effect. Commingled setting decreased recycling contamination significantly but gave no effect on cap removal. In addition, this study found that design effect depended on setting condition of recycling bin. When the PET bottle bin was set together with other recycling bins, signage and all-in-one design significantly promoted cap removal action. Lower recycling contamination of all-in-one design bins is contrast to higher perceptive preference toward separated design. An approach using psychological models in the Theory of Planned Behavior might be useful to explain the gap between perceptive preference toward recycling bin designs and waste separation behavior (Ajzen, 1991; Stoeva and Alriksson, 2017; Xu et al., 2017). On the other hand, signage gave no significant effect on recycling contamination under "together" setting condition. However, it gave significant effect on recycling contamination under "alone" setting when large size wording in the front of recycling bins is considered as signage. Inside-visible design gave no significant effect on both cap removal and recycling contamination regardless of setting condition.

When recycle the cap separately from the PET bottle, this research recommends to reflect the request directly on the recycling bin for PET bottle. A separate recycling bin for cap is unnecessary.

In **Chapter 6,** the effect of past experience on human behavior are limited during the firework events, From the successful experience of Kanazawa and Kamakura firework events, the suitable recycling bins are required to designed with large capacity to manage the large amount of waste generated in a short time. In addition, proper setting location (on the walking pass) based on the surrounding environmental can effective improve the human behavior (waste collection). The volunteer around the recycling bins strongly effect on the waste separation behavior. Based on the theory of planned theory, individual in Japanese culture pay more attention to expectation from significant others in order to maintain good harmony with others (Ando, k., et al, 2010).

In chapter 2 ,3 and 5. The past experience of recycling bins is the important factors influence the human behavior (waste separations and collection) in normal daily life. In addition, according to the results for chapter 4,5, and 6, the setting location of recycling bin is important in the two social environments (daily life and firework events). Proper setting location based on the surrounding environmental can effective improve the human behavior (waste collection).

Overall conclusion

In our daily life, to encourage waste sorting using designed recycling bins, combination of modified design items is necessary and intensive usage of designed recycling bins for frequent perception opportunities recommended to support sufficient design preference. In addition, use the design associate with the waste items is also recommended.

In the specific situation, to encourage the waste sorting using designed recycling bins. design items should be reconsidered according the surrounding environment.

The setting location of recycling bin is important in the two social environments (daily life and firework events). Proper setting location based on the surrounding environmental can effective improve the human behavior (waste collection).

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