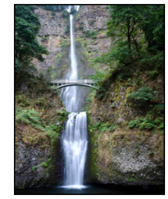
Journal of Environmental Psychology 58 (2018) 77–85

Contents lists available at ScienceDirect

Journal of Environmental Psychology

journal homepage: www.elsevier.com/locate/jep



How does the design of waste disposal signage influence waste disposal behavior?

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ARTICLE INFO

Handling Editor: Florian Kaiser

Keywords:
Recycling
Waste management
Signage design
Behavior change
Best practices
Public policy

ABSTRACT

Despite the ubiquity of waste disposal in urban environments, there is little standardization of receptacle or signage design within and across jurisdictions. In three experiments, we explored the impact of waste disposal signage design on disposal behavior. Specifically, we were interested in two primary questions in signage design: 1) *what* type of waste disposal information should be presented; and 2) *how* the information should be presented. We found that signs containing either icons or pictures of permitted items improved sorting performance compared to signs containing only words of the items; consistent positioning of the signs improved sorting performance compared to random positions for both pictures and icons; and presenting both permitted and prohibited items can interfere with performance when the signs are icons. The current study provides experimental evidence to demonstrate that the design of waste disposal signage can impact waste sorting performance in meaningful ways and highlights the need for graphical signage and bin standardization.

1. Introduction

Waste disposal receptacles and bins are ubiquitous in the urban environment. They are commonly placed in people's homes, offices, and on the streets. The popularity of recycling programs in recent years has led to an increase in waste disposal bin categories (e.g., paper, bottles, compost). This development inevitably requires people to learn to sort their waste in the respective bins, which necessitates new designs of waste disposal signage to help guide users to correctly sort their waste.

Unlike other types of public signs (e.g., traffic signs), there is little standardization among waste disposal signage. Waste disposal signage, the physical appearance of the bins, and the positioning of the bins, differ substantially between neighbouring jurisdictions. Even within the same jurisdiction or institution, there are often diverse signage and bins used in different buildings (Andrews, Gregoire, Rasmussen, & Witowich, 2013). This is problematic given that standardization is an important ergonomic principle known to increase user comprehension and compliance (Ben-Bassat & Shinar, 2006; Shinar, Dewar, Summala, & Zakowska, 2003). The lack of standardization can be confusing and frustrating for users, which leads to improper sorting. Improperly sorted waste increases the costs of recycling programs by increasing the time and labour required to properly re-sort items at a centralized sorting facility or at the pick-up truck (Bohm, Folz, Kinnaman, & Podolsky, 2010).

The research literature suggests that other ergonomic principles should be considered in addition to signage standardization (for example, constructing and placing signs so that they are conceptually and spatially compatible with the message they represent (Shinar et al., 2003)). While there is a wealth of research addressing the components of effective signage in areas like traffic (e.g., Ben-Bassat & Shinar, 2006), industrial safety (e.g. Collins, 1983), consumer safety (e.g. Laughery, 2006), pharmaceuticals (e.g. Chan & Chan, 2013), and even libraries (e.g. Polger & Stempler, 2014), research on waste disposal signs has been limited. Specifically, since an initial study by Austin, Hatfield, Grindle and Bailey (1993) found that the presence of basic signs placed above waste disposal bins can itself increase recycling, the literature has focused largely on persuasive messaging, e.g. "do you leave your litter lying around?", and other design features that might motivate recycling behavior (Bateson, Callow, Holmes, Roche, & Nettle, 2013; Werner, Rhodes, & Partain, 1998; Werner, Stoll, Birch, & White, 2002; Werner, White, Byerly, & Stoll, 2009; de Kort, McCalley, & Midden, 2008). Critically, these studies neither evaluate the design factors of the signs themselves, nor do they investigate how signs might capture attention or communicate the information differently.

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https://doi.org/10.1016/j.jenvp.2018.07.009
Received 13 March 2018; Received in revised form 25 June 2018; Accepted 30 July 2018
Available online 30 July 2018
0272-4944/

The signage literature has adopted a four stage information-processing framework for how signs and labels can produce specific behavioral change: 1) engage attention; 2) facilitate comprehension; 3) modify beliefs and attitudes; 4) enhance motivation (Wogalter & Laughery, 1996). The literature around waste disposal signage has focused on the role of the later stages of this information-processing framework: beliefs and attitudes, and motivation. The first two stages (attention and comprehension) depend on basic design features of the signage that can impact early stages of cognitive processes in a waste disposal context, and they remain unexplored. The present study takes an initial step towards understanding how signs can optimally display information so that users can most efficiently and effectively perceive and comprehend the information presented.

As the motivation behind this study was to assist jurisdictions and institutions wishing to implement evidence-based standardization of waste disposal signage, we were primarily interested in resolving several debates that we found were common across local institutions implementing waste disposal signage. Common concerns included whether words or images were better in conveying the category of waste, whether consistent positioning of the signs was important, and whether signs should display prohibited items (Andrews et al., 2013; Ben-Bassat & Shinar, 2006; Bohm et al., 2010; Schultz, Oskamp, & Mainieri, 1995). From these practical design questions we derived two broad directions that could be explored scientifically: 1) what type of waste disposal information should be presented; and 2) how the information should be presented. Underlying these themes was the larger question of whether basic design features can influence waste disposal behavior at all.

These questions intersect with the established literature on information provision from icons. It has long been noted that icons can communicate large amounts of information efficiently, and are not limited by language barriers (Isherwood, McDougall, & Curry, 2007). In altering attention and comprehension aspects of the information-processing framework, researchers look to manipulate three characteristics of the visual stimuli: complexity, concreteness, and familiarity (McDougall, Reppa, Kulik, & Taylor, 2016). Generally, images that are simpler result in quicker performance, with more complex images resulting in slower response times. There is also a correlation between complexity and familiarity (Forsythe, Mulhern, & Sawey, 2008), though both factors also independently predict performance (with familiarity generally being the most important). Concreteness refers to how pictorial an image is, or how closely it connects or represents the real-world object it is depicting. There remains some debate in the literature about the importance of concreteness in impacting user performance (McDougall et al., 2016).

Recent theory has suggested that easing the information processing of icons (i.e. having simple, concrete, and familiar icons) can not only improve performance (e.g. accuracy and response times) but can also impact subjective evaluations and preferences (McDougall et al., 2016). That is, not only can changing the basic characteristics of visual stimuli make performance easier, but it can also make participants like it more.

The practical questions that motivated our study dovetail with the theoretical questions about the characteristics of visual stimuli, and whether characteristics like complexity and concreteness can impact performance in a novel context – waste disposal – yet to be explored in the icon literature.

To address these practical and theoretical questions, we created an experimental paradigm utilizing motion tracking technology and a large tabletop touchscreen where participants would be shown an item to dispose (e.g. an apple core) and they would then have to throw the item out by touching the proper waste category (compost, paper, recycling, or garbage). Waste categories were represented on the tabletop touchscreen by clear visual signs. We compared the impact of the following factors on sorting behavior: the use of pictures, icons, and texts as signage (Experiment 1), the consistency of bin positions and the presence of permitted and prohibited items (Experiments 2 & 3). We should note that although the relative benefit of icons vs. pictures (vs. words) on human sorting behavior may seem intuitive, the empirical evidence is far from clear-cut. Designing effective visual signage in many ways is about striking the proper balance between presenting too little and too much information to guide the sorting behavior (e.g., Cole, Hammond, & McCool, 1997; Hollnagel, 2009). The pictures and icons used in our experiments were developed with the diverse images commonly found throughout the local municipalities' waste disposal signage. We used the same four waste streams that were ubiquitous on the campus of University of British Columbia and in the local communities. The sorting rules in the experiments followed the sorting guidelines in the City of Vancouver. As the participants would have to reach out to the sign to dispose an item, the task approximates the reaching gestures commonly used when throwing out a waste item in the real world. We reasoned that natural responses such as these might generalize more readily to actual sorting behavior outside the laboratory, yet the tabletop set-up allowed us to easily manipulate the design of the signs while controlling for all other external factors.

2. Experiment 1

We began by exploring whether different types of image renderings (pictures, icons, words) would be more effective at inducing proper waste disposal behavior. The literature suggests that signage information conveyed by images generally produce better outcomes than those by words only, which has led some regulators to replace word-only warning signs with images (Argo & Main, 2004; Forsythe, Sheehy, & Sawey, 2003). We predicted, therefore, that images should produce faster and more accurate responses compared to words.

2.1. Methods

2.1.1. Participants

Psychometric visual cognition studies that emphasize speed and accuracy routinely sample 15–30 participants in order to obtain a reliable measure of central tendency (Baddeley, 2003; Grill-Spector & Kanwisher, 2005; Wolfe, 1998). The present series of experiments were grounded on this foundation. Furthermore, a power analysis was conducted using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007). Given a partial eta squared of 0.41 (Luo, Zelenika, & Zhao, under review; Zhao, Al-Aidroos, & Turk-Browne, 2013) derived from our previous work using a similar interface and experimental design with four within-subjects conditions, a minimum of 20 participants was required to have 90% power (alpha = 0.05) to reveal an effect. Thus, we recruited at least 20 participants in each experiment. Variation in the number of participants beyond this threshold is inevitable based on how the University of British Columbia subject pool operates, where studies are open for a set period of time, and students are free to sign-up for course credit or financial remuneration both for the purpose of contributing to new data acquisition and in order to gain personal insights into how research investigations operate. Thus, if the number of volunteers exceeds our pre-set target, we allow them to participate and, of course, include their data in our analyses.

In our first experiment forty-three university students (mean age = 23.42 years, sd = 4.94, range = 18–42; 13 male; 40 right handed) participated in a 30-min session for course credit or $5 CAD. We excluded one subject because of an equipment failure that occurred during testing.

2.1.2. Stimuli

Four waste categories were used: garbage, recycling, paper, and compost. Each waste category was represented by a sign. Signs were

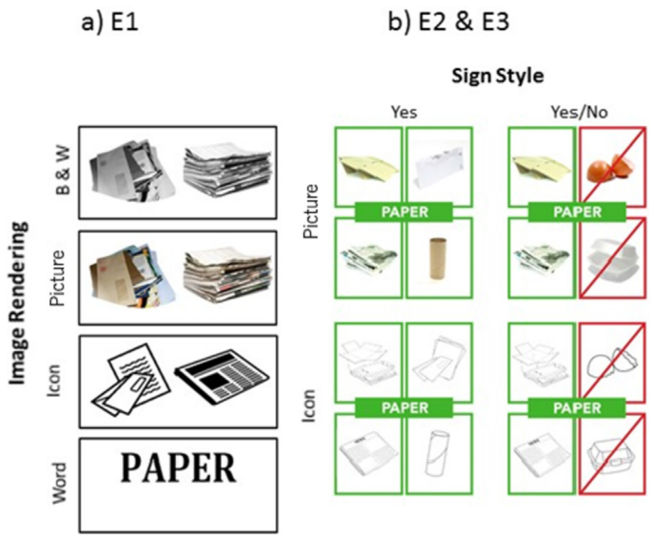

Fig. 1. Example of the signs used (paper waste category shown) for each image rendering in (a) Experiment 1, and for each combination of Image Rendering and Sign Style in (b) Experiment 2 and Experiment 3.

depicted using four different image renderings (standard pictures, black and white pictures, icons, or words). These image renderings allowed us to manipulate the level of complexity and concreteness of each sign. Standard pictures were the most complex and most concrete (most accurately portrayed real-world items). Black and white pictures were less complex though still displayed the same level of concreteness as standard colour pictures. Icons meanwhile were less complex and concrete than the pictures (see Fig. 1). These signs displayed items that were representative of the category and also found commonly in waste disposal signs in the local area. As such, only a few items to be disposed of matched the items displayed on the signs. Not all items displayed on signs were items participants were tasked to dispose of. Participants were tasked to dispose of a total of 96 items during testing, with 24 items drawn from each of the four categories: compost, garbage, paper, and recycling categories. The items to be disposed of were presented as word labels to limit ambiguity of what the items were. See Appendix 1 for a list of the items that were to be disposed of and the items that were displayed on the signs.

2.1.3. Apparatus

A motion tracking setup was used for this experiment, which consisted of 6 motion tracking cameras (NaturalPoint Optitrack, VR100:R2), each with a 100 Hz sampling rate and 640 × 480 pixels spatial resolution. These cameras emitted infrared signals to detect a small marker ball that was attached to a participants' index finger with an adjustable strap. The stimuli were projected onto a tabletop from a ceiling-mounted projector (Dell M410HD) with display settings of 1024 × 768 pixels and 60 Hz refresh rate. The physical size of this projected area on the table was 92 cm × 69.25 cm. See Fig. 2 for how the signs were displayed and the dimensions of the projected area. Motion tracking data, including reaction times and reach times, were collected and the experiment was controlled using MATLAB. See Fig. 3 for a depiction of the Optitrack setup.

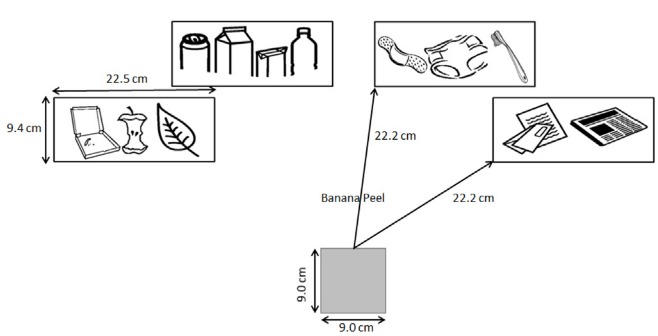

Fig. 2. An example of the display a participant would see before making their bin choice in Experiment 1 with dimensions included.

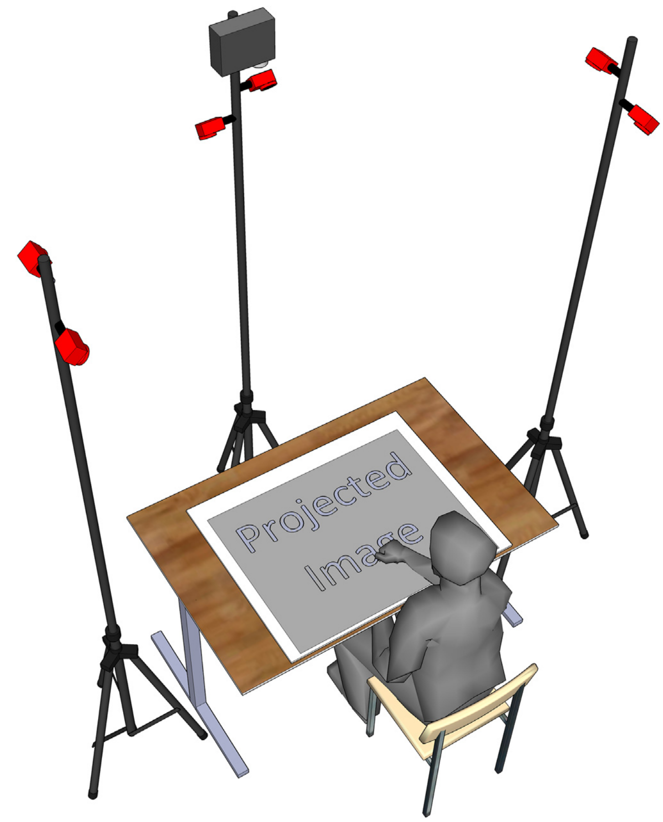

Fig. 3. Optitrack setup used in this study.

2.1.4. Procedure

Participants[1] were seated at the touch table, and were fitted with an adjustable marker on the index finger of their dominant hand. On each trial, a home box appeared first. Participants held their index finger down within the home box for 1 s, after which an item to be disposed of would be randomly selected and appear 6.6 cm above the home box. Participants were given ample time (3–4 s) to decide what waste category the item belonged to, before the different waste bins appeared in any one of four possible locations. In this way any variation between bin selection (e.g., words vs. images) could be attributed to differences in processing the bin. Participants then indicated which Waste Category the item should be deposited in by reaching out and touching down on the sign, roughly simulating a natural "throwing away" gesture. To emphasize that we wanted participants to behave naturally, we asked participants to "imagine themselves placing various waste items in the right disposal bin" by reaching towards and touching down on the correct sign. We emphasized that both the speed and accuracy of their reaches were important. Note that if participants lifted their finger outside the home box before the bins appeared, the trial ended prematurely and the participant received a "too early" message; that item's

[1] Half of the participants in the study underwent a cognitive load manipulation, whereby on each trial they were asked to hold in working memory a various set of different colors. However, this load manipulation had no impact on sorting performance in this experiment and the conditions were collapsed for all subsequent analyses.

position in the sequence would then be re-randomized along with the remaining items to be disposed of. There was a 2.5 s interval between trials.

2.1.5. Data handling

"Efficiency score" was our main dependent variable (Townsend & Ashby, 1983). This measure was computed by dividing the total reaction time (the time it took from when a participant lifted his or her finger from the home box to when a sign was touched) by accuracy (the proportion of accurate responses). It is well established that response accuracy is often sacrificed in the name of response speed, known as the speed-accuracy trade off (Bogacz, Wagenmakers, Forstmann, & Nieuwenhuis, 2010; Wickelgren, 1977). Efficiency scores seek to normalize this trade off by taking into account both reaction time and accuracy, allowing us to normalize different speed-accuracy response strategies (e.g., maximizing speed at the cost of response accuracy versus sacrificing speed in order to respond accurately). Thus, for example, if a person took 1 s (1000 ms) to respond but only got half of the responses right, their efficiency score would be 2000 (1000 ms/0.5 = 2000); whereas if another person took 1 s to respond but got all the responses correct, their score would be 1000 (1000 ms/1 = 1000). Thus, better performance is reflected in a more efficient (smaller) efficiency score. Response times were trimmed according to a hybrid recursive trimming method in order to remove outliers including trials with extremely short or long response times (Van Selst & Joliceour, 1994). This procedure removed on average 3.60% of trials.

2.2. Results

Efficiency scores were calculated for each participant (ms/accuracy), and then entered into a within-subjects ANOVA across the four levels of Image Rendering. There was a main effect of Image Rendering ($F_{(3,\ 123)} = 6.9$, $p < .001$, $\eta_p^2 = 0.14$). Paired t-tests on all pairs of means with bonferroni adjusted p-values for multiple comparisons revealed that word renderings produced significantly worse total efficiency scores than standard picture renderings (*mean difference* = 1098.5, *std. error* = 371.4, $p = .031$, $d = 0.46$, *0.95CI* = [68.7, 2128.2]), and worse than black and white renderings (*mean difference* = 948.7, *std. error* = 334.9, $p = .043$, $d = 0.44$, *0.95CI* = [20.1, 1877.2]). All other pairs of image renderings were not significantly different (*p values* > .06), though it is noteworthy that words were also almost significantly worse than icons (mean difference = 893.2, *std. error* = 332.4, $p = .062$, $d = 0.41$, 0.95CI = [−28.2, 1814.6]). The underlying reaction time and accuracy scores are reported in Table 1. Table 2 reports the descriptive statistics based on item category.[2]

2.3. Discussion

In Experiment 1, we examined what type of waste disposal information should be presented in the signage of each waste category, in order to maximize people's sorting performance. Specifically, we examined whether waste disposal signs were more effective when they consisted of images or words. Based on previous literature, we predicted that images would fare better than word-only signs as, for example, traffic signs with symbols are not only learned more quickly, but also produce more accurate recall compared to word traffic signs (Walker, Nicolay, & Stearns, 1965). Similarly, in categorization tasks, images tend to show a general behavioral benefit over words (Snodgrass & Vanderwart, 1980). Consistent with these data the results from Experiment 1 reveal that picture and icon signs yield more efficient performance than word-only signs (though only marginally in the case of icons).

The differences in image and icon signs appeared not to matter. Looking at the descriptive statistics, standard picture images had the fastest reaction times despite being the most complex sign. This might suggest that there is some advantage of concreteness in situations where the task and the signs are unfamiliar (McDougall et al., 2016). However, given that the accuracy was similar across all three categories, the results of Experiment 1 suggest that any differences between the three categories may not have any substantial practical implication.

In summary our data suggest that sign designers for waste disposal should opt for images over words. However, it is important that designers keep in mind that the superiority of images over words may not apply to all situations. In some cases, when the words are highly familiar (as in 'Push' and 'Pull'), or the images themselves are novel or unfamiliar, words may be preferable to images. Of course, images also carry other advantages, such as being able to circumvent language barriers (Walker et al., 1965).

Table 1
Mean (± SD) efficiency scores with underlying average reaction time and average accuracy scores for Experiment 1.

	Picture (Black and White)	Picture	Icon	Word
Response Time (ms)	2120.2 (± 805.4)	1992.9 (± 677.4)	2141.4 (± 804.3)	2310.2 (± 1146.3)
Accuracy (% correct)	75.2 (± 8.4)	75.9 (± 11.0)	75.2 (± 10.1)	70.2 (± 16.6)
Efficiency Score	2885.1 (± 1178.7)	2735.3 (± 1276.9)	2940.5 (± 1272.6)	3833.7 (± 2940.1)

Table 2
Mean (± SD) efficiency scores with underlying average reaction time and average accuracy scores based on item category for Experiment 1.

	Compost	Garbage	Paper	Recycling
Response Time (ms)	2127.5 (± 901.4)	2402.3 (± 1000.7)	1917.7 (± 773.4)	2141.1 (± 797.9)
Accuracy (% correct)	69.2 (± 15.1)	73.0 (± 16.5)	77.1 (± 15.7)	77.1 (± 16.6)
Efficiency Score	3328.0 (± 1886.7)	3661.0 (± 2217.6)	2798.9 (± 1977.5)	3052.1 (± 1767.2)

3. Experiment 2

In Experiment 2, we move onto the second question: how should the information be displayed? As previously mentioned, standardization (i.e., consistency in design features across repeated uses) is an important ergonomic principle known to increase user comprehension (Ben-Bassat & Shinar, 2006; Shinar et al., 2003). In the visual search context, researchers have long known that knowledge of different attributes of the target can guide search behavior in a "top down" manner and decrease search times (Wolfe, 2007). For example, consistent spatial arrangements have been shown to aid visual search in experimental situations (Chun & Jiang, 1999; Conci, Sun, & Müller, 2011). As spatial positioning of waste disposal items is something that could be standardized but tends to vary across situations, we reasoned that this design feature is worthy of investigation.

Experiment 2 also begins to explore whether designs showing prohibited items, as well as permitted items, improves performance. While

[2] The low number of observations per cell makes reporting inferential statistics based on item category problematic (the inability to perform the hybrid recursive trimming procedure, the increased likelihood of having an accuracy of zero in a category, etc.) We report the descriptive statistics for interest only, as we believe it would be fruitful for subsequent studies to explore which item categories are most problematic to dispose of.

Fig. 4. Real-world examples of waste disposal signs displaying both allowed and prohibited items.

signs that display prohibited items provide more information (e.g. Arphorn, Augsornpeug, Srisorrachtr & Pruktharathikul, 2003; Kline & Beitel, 1994) they also risk increasing selection difficulty (i.e., necessitating that the user correctly discriminate between permitted versus prohibited items), and may lead to confusion, errors, and/or slower decisions (Forsythe et al., 2003; Kline & Beitel, 1994). To our knowledge, despite the popularity of such signs, the benefits of including prohibited items on waste disposal signs have yet to be identified (see Fig. 4 for real-world examples of signs showing permitted and prohibited items).

In Experiment 2, we tested the efficacy of such signs by having them depict permitted items only ("yes" signs) or both permitted and prohibited items ("yes/no" signs). To maintain a consistent trial and analysis structure with Experiment 1, we included only two Image Renderings (pictures and icons) with our two Sign Styles (yes signs and yes/no signs), for a total of four sets of signs. We also had a consistent condition where the position of the waste categories stayed the same, and a random condition where the position of the categories was randomized in each trial. Category condition was manipulated between-subjects, and sign style was manipulated within-subjects.

3.1. Methods

Except where noted, the methods used were the same as in Experiment 1.

3.1.1. Participants

Twenty university students (mean age = 20.9, sd = 3.3, range = 17–30; 15 female; 18 right handed) participated in a 30-min session for course credit or $5 CAD. The participants were randomly assigned to two different consistency conditions: half were in a Consistent Condition where the locations of the Waste Category were the same for every trial, while the other half were put in a Random Condition where the locations of the waste category were randomized on every trial.

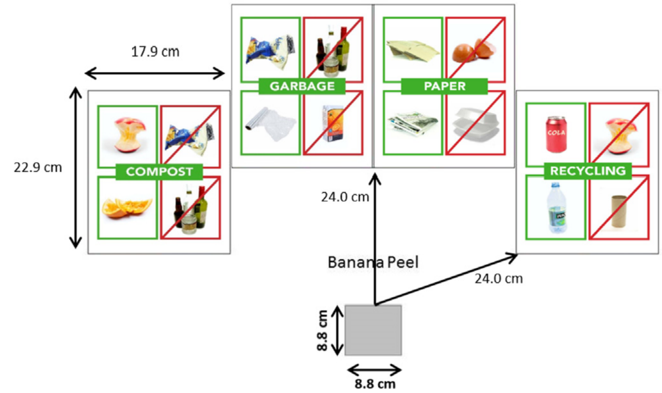

Fig. 5. An example of the display a participant would see before making their bin choice in Experiment 2 with dimensions included.

3.1.2. Stimuli

Signs were designed for us by Metro Vancouver, British Columbia, Canada in a 2 (Sign Style: yes vs. yes/no) x 2 (Image Rendering: picture vs. icon representations). The signs were developed to be as ecologically valid as possible (i.e., they were designed to look like signs that users may actually see in real life) while still meeting our experimental needs (see Fig. 1b for signs, and Fig. 5 for dimensions).

3.1.3. Trial structure

Trials were randomized such that there were 24 trials for each of the 4 sign conditions (2 Sign Styles x 2 Image Renderings). In the Random condition each possible spatial positioning of compost, garbage, paper, and recycling categories were shown in the 24 trials. In contrast, the Consistent Condition always displayed the waste categories in the following order, from left to right: garbage, paper, recycling, compost. For both groups the actual order of the items to be disposed was randomized. Participants were given 1.8s to select a sign before the trial would end and be reshuffled together with the remaining trials.[3] Testing occurred in two blocks of 48 trials, separated by an untimed rest break.

3.1.4. Data handling

As with Experiment 1, efficiency scores were calculated for each participant (ms/accuracy). The hybrid recursive trimming procedure removed on average 3.10% of trials.

3.2. Results

A 2 × 2 × 2 ANOVA was conducted with Sign Style (yes, yes/no) and Image Rendering (picture, icon) as within-subjects factors, and Consistency Condition (consistent, random) as a between-subjects factor. The results are presented in Table 3. It is clear from the table of means that consistent sign positions produce better efficiency scores than random sign positions (*mean difference* = 730.4, $F_{(1,\ 18)} = 14.8$, $p < .01$, $\eta_p{}^2 = 0.45$, $d = 0.98$). All other main effects, and interactions were not significant (*p*'s > .14), with image rendering, as in Experiment 1, falling short of significance ($F < 1$). Note, however, an interesting spike in response inefficiency for the random positioning of an iconic yes/no sign (*mean efficiency* = 1969), though the 3-way interaction fell far short of significance ($F_{(1,\ 18)} = 0.3$, $p = .60$, $\eta_p{}^2 = 0.02$).

[3] The 1.8s cutoff was chosen as we found that during pilot testing, it was approximately the lower limit within which participants could still accurately respond.

Table 3
Mean (± SD) efficiency scores and underlying average reaction time and average accuracy scores for Experiment 2.

	Picture		Icon	
	Yes	Yes/No	Yes	Yes/No
Consistent Position				
Reaction Time (ms)	761.1 (± 162.2)	763.2 (± 182.8)	797.2 (± 186.0)	780.7 (± 176.4)
Accuracy (% correct)	73.3 (± 12.5)	77.1 (± 13.5)	80.4 (± 6.5)	77.1 (± 13.6)
Efficiency Score	1114.8 (± 577.9)	1062.0 (± 536.3)	1008.7 (± 321.7)	1082.0 (± 506.6)
Random Position				
Reaction Time (ms)	1204.4 (± 157.1)	1220.9 (± 127.4)	1229.5 (± 130.5)	1215.5 (± 110.7)
Accuracy (% correct)	70.8 (± 11.1)	72.9 (± 11.7)	71.7 (± 11.8)	65.4 (± 14.0)
Efficiency Score	1757.0 (± 468.4)	1707.2 (± 277.5)	1755.9 (± 351.8)	1968.9 (± 638.5)

3.3. Discussion

In Experiment 2, we investigated how consistent spatial positioning of signs, and how depicting both permitted and prohibited items could impact waste disposal behavior. As predicted by the literature, we found that consistent positioning of the signs led to better sorting performance than random positioning of the signs. This suggests that standardization of bin position should be prioritized for jurisdictions and institutions seeking to reduce contamination in waste disposal bins. It also highlights the difference between situations where there are built-in waste receptacles (e.g. in some food courts; Wu, DiGiacomo, & Kingstone, 2013) that maintain the relative location of the waste bins versus situations where waste disposal receptacles are individual bins that may have their relative positions changed (e.g., in many office buildings; Duffy & Verges, 2009). Our results indicate that the former is preferable to the latter.

As in Experiment 1, we found no difference in sorting performance between image renderings (picture/icons); and we also found no effect of sign style (yes vs. yes/no). However, there was an intriguing (though statistically irrelevant) suggestion that sign style itself might interact with image rendering if the arrangement of the bins is not consistent, with sorting efficiency declining for the yes/no iconic signs.

In considering the potential import of this issue, we noted that the ordering of the yes/no sign information was always consistent in Experiment 2, with 'yes' consistently appearing on the left and 'no' on the right. Given that bin consistency enhances sorting efficiency and mitigates any sign style × rendering interaction, we thought it important to investigate if yes/no sign consistency also modulates performance, and if it does, will it interact with sign rendering as hinted at in Experiment 2. We pursued this final issue in Experiment 3.

Table 4
Mean (± SD) efficiency scores and underlying average reaction time and average accuracy scores for Experiment 3.

	Picture		Icon	
	Yes	Yes/No	Yes	Yes/No
Reaction Time (ms)	1252.2 (± 122.1)	1280.3 (± 138.4)	1262.2 (± 100.6)	1322.0 (± 186.7)
Accuracy (% correct)	69.4 (± 12.2)	74.4 (± 9.8)	75.5 (± 9.2)	72.3 (± 11.5)
Efficiency Score	1852.8 (± 335.9)	1757.8 (± 347.8)	1702.8 (± 310.1)	1878.1 (± 413.9)

4. Experiment 3

While Experiment 2 focused on the spatial positioning of the global arrangement of waste categories, the current experiment focused on the spatial positioning of the items within the signs themselves for each bin. Thus, waste bin categories were randomized, and the spatial positions of the yes items and no items were counterbalanced and Sign Style (yes vs. "yes/no" for one group, yes vs. "no/yes" for the other group). In light of our observation that response efficiency may be compromised for yes/no icon signs we expected that randomization on yes/no consistency may be most evident for the iconic images.

4.1. Methods

Except where noted, the methods used were the same as in Experiment 2.

4.1.1. Participants

Twenty-six university students (mean age = 20.0 years, sd = 2.7, range = 18–29; 22 female; 24 right handed) participated in a 30-min session for course credit or $5 CAD.

4.1.2. Stimuli

Half of the yes/no signs in this experiment had yes items on the left and no items on the right, and the other half had the reverse, with waste category randomized across trials and yes/no order counterbalanced across participants. Otherwise, the stimuli were the same as in Experiment 2.

4.1.3. Trial structure

All participants had randomized spatial positioning of the waste categories for every trial. Otherwise, the trials were the same as in Experiment 2.

4.1.4. Data handling

The data were handled as before. The hybrid recursive trimming procedure removed on average 2.00% of trials.

4.2. Results

A 2-way within-subjects ANOVA was conducted on efficiency scores, with Sign Style (yes vs yes/no) and Image Rendering (picture vs icon) as within-subjects factors.[4] The results are presented in Table 4. There was a significant interaction of Sign Style x Image Rendering ($F_{(1,25)} = 7.7$, $p < .05$, $\eta_p^2 = 0.24$). However, the main effects of Sign Style and Image Rendering factors were not significant (*F's* < 1). To investigate the source of the interaction, we conducted two paired t-tests with the Bonferroni correction for multiple comparisons. The difference between yes and yes/no styles for the icon rendering was significant (*mean difference* = 175.3, *std.error* = 68.1, $p < .05$, $d = 0.50$, *0.95CI* = [12.9, 337.7]). However, there was no statistically significant difference between yes and yes/no styles for the picture Rendering (*mean difference* = −95.0, *std.error* = 87.1, $p = .57$, $d = 0.21$, *0.95CI* = [−302.7, 112.7]).

4.3. Discussion

This experiment revealed that iconic yes/no signs results in less efficient response decisions than iconic yes signs. In contrast, response efficiency for pictures was the same for yes/no and yes signs. This

[4] When we analyzed the ANOVA including the between groups factor of yes/no positioning (yes/no vs. no/yes), we found no significant effects or interactions involving this manipulation (all p values > .16), thus we collapsed the group variable and analyzed Sign Style x Image Rendering.

pattern of results confirms the observation hinted at in Experiment 2.

Why should yes/no iconic signs interfere with response efficiency? We suggest that it is because the colour used to convey yes/no response information is especially salient for iconic signs, as they are otherwise colourless, drawing attention to colour and away from the waste category form information. In short, the conspicuity of the colour information in the iconic renderings can distract attention away from the form information that is necessary to first make the correct waste category selection. There is a wealth of controlled studies demonstrating precisely this result (see Theeuwes, 2004; Theeuwes & Godijn, 2001; Theeuwes, Kramer, & Kingstone, A., 2004; Yantis, 1996).

5. General discussion

Motivated by questions commonly encountered in jurisdictions and institutions seeking to reduce waste, this study sought to examine how signage might affect waste disposal behavior in two ways: 1) what type of information is conveyed; and 2) how the information is conveyed.

In Experiment 1, we found that signs conveying information with images or icons are better than signs conveying information with only words. In Experiments 2 we found that displaying prohibited items along with permitted items did not yield a net benefit relative to signs that only contained permitted items, although consistent positioning of the four waste categories enhances sorting performance. Experiment 3 picked up on the possibility that when bins are randomized, yes/no signs may actual interfere with response efficiency for iconic signs. This possibility was tested, and confirmed, in Experiment 3.

Collectively our experiments show that some basic design features of signs can have an impact on sorting performance, specifically, whether the signs use words or images and whether the signs are consistently positioned. The increased sorting efficiency (improved accuracy and reduced response time) suggests a potential lower ecological footprint because higher sorting accuracy means reduced contamination in the waste streams, particularly in the compost, recycling, and garbage streams. Less contamination in the compost, recycling, and garbage streams means that there is more waste diverted from landfill and more materials to be re-used (Hoornweg, Bhada-tata, & Kennedy, 2013; Zelenika, Moreau, & Zhao, 2018). However, not all changes have a profound impact. We found that adding prohibited items to the signs did not improve a signs' ability to influence response decisions, and can, in the case of icon signs, interfere with response behavior. On this latter point we think it prudent to emphasize that there may also be a point at which yes/no signs for pictures also compromise decision making. Yes/no signs convey more information than yes signs alone, and too much information can result in less attention being devoted to any one item, and with this the ability to comprehend and retain information declines – i.e., "information overload" (Cole et al., 1997; Rosenholtz, Li, & Nakano, 2007). It seems inevitable that displaying too much information on a waste disposal sign (e.g., displaying a large number of permitted and prohibited items) will, at a certain point, lead to information overload and impair performance. To the extent that yes/no signs double the amount of information on yes signs, the former risk impairing sorting performance more than the latter.[5] In our view, waste disposal signage should be simple and comply with ergonomic principles like being brighter, having less clutter, and having larger font (Argo & Main, 2004; Ben-Bassat & Shinar, 2006; Campbell, Cowley, Mayhorn, & Wogalter, 2007; Wogalter, Conzola, & Smith-Jackson, 2002). Unfortunately, many of these yes/no signs encountered in the real world are extremely cluttered with far more information being displayed than those in the present study (see Fig. 4 above).

Furthermore, we think that it is appropriate to ask if, and to what extent, our findings will replicate across different demographics and cultures, as well as sorting behaviours in the real-world context. There is no question that exploring the boundary conditions of lab-based investigations drawn from a particular population sample is of importance (Anderson, Lindsay, & Bushman, 1999; Falk & Heckman, 2009; Mitchell, 2012), but we have good reasons to expect our present findings to apply to a broad and diverse range of individuals and real-world settings. First, our study, while controlled, struck an important balance between control and real-world relevance, by using sorting signage drawn from the local community and sorting guidelines from the City of Vancouver, which itself is extraordinarily diverse. Second, our paradigms used motion tracking technology which required participants to pick up the item and place it into one of the bins. This paradigm was designed to mimic real-world sorting behavior. Finally, the effects observed in our study reflect differences between conditions within the same participants (i.e., within-subject effects), which means that our findings are less susceptible to individual or cultural differences. Even when comparisons were between-subjects, participants were randomly assigned to each condition, which means that any variation between individuals should be equal in each condition.

While the information provision literature on the effectiveness of icons and images has long known that basic changes in the characteristics of visual stimuli can affect information processing and therefore user performance, our study applies this theory into a novel context – waste disposal – where we find an avenue to make what at times can be a difficult and confusing task (sorting waste) unconsciously easier by altering the characteristics of signs.

5.1. Conclusion and future directions

Our experiments reveal that basic design features of waste signage can influence the efficiency of sorting behavior. We began answering questions found commonly across institutions seeking to standardize waste signage in order to facilitate sorting behavior. Despite our experiments being only exploratory in nature, they help inform institutions in their decisions regarding the creation of effective waste disposal signage.

This series of experiments represents an initial and exploratory step towards creating standardized waste disposal signage. Many questions remain unanswered. For example, there appear to be cultural differences in the comprehension of traffic signs (Shinar et al., 2003). Do such differences also exist in waste disposal signage? This is an important question for highly multicultural jurisdictions such as New York and Chicago in the USA, and Toronto and Vancouver in Canada. Subsequent studies could also look at whether increasing the ease of information processing of waste disposal signs can also influence the subjective appeal of the signs and the task, as has been recently demonstrated in other contexts (McDougall et al., 2016). Making both the task of disposing waste *easier* and more *attractive* can have profound practical implications. Another useful next step will be to test how waste signage influences behavior in uncontrolled real-world settings, as opposed to the present controlled environment (see e.g. Kline & Beitel, 1994), since waste disposal behavior in the real world can differ drastically from experimental settings (Wu, DiGiacomo, Lenkic, Wong, & Kingstone, 2016). Critically, the present study provides an empirical framework within which findings in the natural world can be contextualized.

The impact of "familiarity" of signs has yet to be explored in the waste disposal context. Given literature suggesting that familiarity is perhaps the most important characteristic of icons in impacting user performance, the study and creation of standardized waste disposal signs are, in our view, critically important.

[5] Indeed, in an early pilot experiment (N = 25) with cluttered signs displaying much more information than in the experiments in this study, we discovered that performance with yes/no signs led to significantly worse sorting efficiency than yes signs.

Acknowledgements

This research was supported by grants to AK from the Natural Sciences and Engineering Research Council of Canada, and the Social Sciences and Humanities Research Council of Canada.

Appendix

A list of the items that were presented to participants for disposal. Items in bold were shown on the signs in Experiment 1, and items in italics were shown on the signage in Experiments 2 and 3.

Compost	Garbage	Paper	Recycling
Apple core	Baby wipes	Calendar	Applesauce cups
Bones	Balloons	*Cardboard box*	Bread bag
Bread	**Bandages and gauze**	Catalogue	Cardboard container
Cake	Candle	Cereal box	Coffee can
Candy	*Cellophane (plastic wrap)*	Cigarette package	Coffee cup lid
Cereal	*Cracker wrapper*	Detergent box	Cookie tin (empty)
Cheese	Dental floss	***Letter Envelope***	Cottage cheese tub
Coffee cup	**Diaper**	File folders	Frozen juice container
Coffee filter	Elastic bands	Flyers	*Glass bottle*
Coffee ground	Freezie wrapper	Frozen dinner box	Household Cleanser bottle
Eggs/eggshells	Frozen Dinner Plastic Food Tray	Gift Boxes	***Juice box***
Food scraps	Lollipop stick	Greeting card	**Juice carton**
Hamburger meat	Make-up	**Junk mail**	Margarine tub
House plants	Pads from meat trays	Magazine	Metal Coffee Can
Nuts and shells	Pen	***Newspaper***	Plastic milk carton
Oatmeal	Pencil	Paperback Book	Paint can
Orange peels	Soap	Phone book	Plastic bottle
Paper napkin	Stapler	Postcard	Plastic jug for detergent
Paper towel	Pet waste	Poster board	***Plastic water bottle***
Pasta	Plastic straw	Posters	***Pop can***
Peanut butter	*Potato Chip bag*	Shoe box	Shampoo bottle
Pizza Box	Tim Hortons iced cappuccino cup	Tissue box	Sour cream tub
Take out container from UBC Food Services	**Toothbrush**	Tissue wrapping paper	Steel soup can
Tea bag	Toothpaste tube	*Toiletpaper tube*	Yogurt tub

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