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Enabling desired disposal of compostable plastic packaging: an evaluation of disposal instruction labels

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Introduction: This study evaluated a series of disposal instruction labels for their effectiveness in enabling the desired disposal of compostable plastic packaging.

Methods: Mixed methods were employed: an online experiment and a survey. UK citizens (n = 1,008) completed a task, sorting packaging labelled with various disposal instructions into one of three bins (general waste, food waste, and recycling). They also selected a preferred compostable disposal instruction logo and provided reasons for their preference.

Results: Items lacking disposal instructions followed intuitive disposal practices: items with a common practice of being compostable were most frequently disposed of into food waste; items with a common practice of being recycled were most frequently disposed of into recycling; and items with a common practice of being disposed of with general waste were most frequently disposed of with general waste. "Do not recycle" was effective at diverting compostable plastic packaging to general waste. The label "compost with food waste" had the highest rate of correct disposal in the food waste bin when compared to the control group and to the "compost" disposal instruction. "Compost with food waste", however, was not statistically different from "put with food waste" or "recycle with food waste"; all three led to statistically similar disposal rates in the food waste bin. Qualitative findings showed that participants preferred clarity and directness in the disposal instructions logo denoting compostability.

Discussion: Findings suggest that citizens struggle to identify compostable plastic packaging from appearance alone. Clear direct disposal instruction wording can help enable the appropriate disposal behaviours. Qualitative findings showed that participants preferred clarity and directness in the disposal instructions logo denoting compostability. The depiction of simple yet unambiguous and instructive symbols was valued and likely to be the better instigators of behaviour change compared with associative symbols. Implications for labelling policy are discussed.

KEYWORDS

behaviour change, circular economy, compostable plastic, consumer behaviour, disposal, intervention, plastic packaging, recycling

1 Introduction

Compostable plastics are growing in popularity as they promise a solution to the plastic waste crisis, particularly in terms of reducing waste from single-use plastic packaging. The current bioplastics market share is relatively small at <1% of the total 390 million tons of plastics produced globally; however, this figure is continually growing as applications of bioplastics evolve. The global production capacity for biodegradable plastics is set to increase from approximately 2.2 million tonnes in 2022 to approximately 6.3 million tonnes in 2027 (European Bioplastics, 2022a). There are, however, some fundamental problems, particularly in the UK.

These materials have become the "Wild West" of the packaging sector in that they are largely unregulated. There are issues with standards and certification, with limited rules around how they are labelled and marketed; manufacturers and suppliers are, therefore, at liberty to market them as they please. As effective systems for collecting, sorting, and processing compostable plastics are rare in the UK, the most frequent outcome is landfill or incineration, leading to confusion and mistrust of the environmental claims made of compostable plastics (Purkiss et al., 2022).

A further issue is that the terms "bioplastic", "compostable", "biobased", and "biodegradable" are often used interchangeably, making it challenging to make sense of and accumulate the evidence. The terms have distinct meanings and nuanced differences. In the present study, we define these terms in line with European Bioplastic's definition of bioplastics (European Bioplastics, 2022b) and the definitions of EU of compostable, biobased, and biodegradable plastics (European Commission, Directorate-General for Research and Innovation et al., 2020; European Commission, 2022). "Bioplastic" comprises a family of materials with different properties and applications as summarised in Table 1.

"Biobased" describes the source of the material at the start of the lifecycle of the plastic. Biobased plastics are fully or partially made from biological resources, rather than fossil raw materials. Biobased plastics are not necessarily biodegradable or compostable, terms which refer to how the material degrades at its end of life. The main difference between "biodegradable" and "compostable" in the context of plastic is that biodegradable plastic can take an undetermined time to break down. In contrast, compostable plastic must degrade, within a given timeframe, under specified composting conditions. There are different nationally and internationally accredited certifications assessing the credentials of compostable packaging. For a summary of these, the reader is referred elsewhere (e.g., Allison et al., 2022).

For the scope of this study, we are concerned with "compostable" plastics as "compostable" refers to a specific type of material that needs to be managed through specific routes. It thus allocates a clearer role to citizens as people responsible for sorting and disposing of waste through specific waste management routes, e.g., organic waste collection services.

Compostable plastics could be part of a sustainable UK packaging system; however, this would require UK citizens to adopt the appropriate waste management behaviours that lead to the materials being composted, i.e., putting those in the correct bin for processing (see Figure 1). Incorrect disposal offsets any of the potential environmental benefits of compostable plastic packaging. As compostable plastics are relatively new in terms of an integrated UK waste management strategy, there is little research to inform the design of behaviour change interventions to increase appropriate waste management of these materials. This study aimed to address this gap by investigating how to promote the desired disposal of compostable plastic packaging.

Prior research on behaviour concerning compostable plastic disposal has largely focussed on the confusion surrounding "biobased", "biodegradable", and compostable plastics, identifying the need for clear, explicit, and instructive messaging on packaging (Sijtsema et al., 2016; Herbes et al., 2018; Dilkes-Hoffman et al., 2019). Evidence suggests that "biodegradable" is a confusing term as it offers little guidance on how to dispose of items (Allison et al., 2021; Purkiss et al., 2022). Studies in Germany (Taufik et al., 2020) and Netherlands (Ansink et al., 2022) show this confusion leads to incorrect disposal in practice. In the German study, the majority of participants (63%) disposed of this type of packaging in recycling rather than with organic waste, the correct option for that context. Even amongst those who observed the logos and disposal instructions on the packaging, these items were incorrectly disposed of. The reasons provided for their disposal decisions included the messaging being unclear or that they did not believe that plastic water bottles could be compostable. The Dutch study showed that only 35% of participants observed the logos on the packaging meant to communicate information about product biodegradability. Even amongst those who did observe the logos, these materials were usually incorrectly placed in recycling rather than residual waste, the correct option for that context.

While the evidence is clear that citizens struggle to dispose of these items correctly, it is unclear which types of messaging might promote desired disposal. These studies only tested one type of packaging format: plastic water bottles in the German study (Taufik et al., 2020) and plastic cups in the Dutch study (Ansink et al., 2022). The material more commonly used for the production of bottles or containers for beverages is polyethylene terephthalate (PET), and as PET is a recyclable material, the recycling bin would be the right bin (Nisticò, 2020). It is therefore important to conduct further studies testing a variety of packaging formats to minimise the potential confounds of past associations with a particular type of packaging.

TABLE 1 Table of definitions for bioplastic, biobased, biodegradable, and compostable plastic.

Term	Definition	Source
Bioplastic	Plastic material is defined as bioplastic if it is either biobased, biodegradable, or features both properties.	European Bioplastics (2022b)
Biobased	Biobased plastics are fully or partially made from biological resources, rather than fossil raw materials. They are not necessarily biodegradable or compostable.	European Commission (2022)
Biodegradable	Biodegradable plastics biodegrade in certain conditions at their end of life. Biodegradable plastics may be made from biological resources or fossil raw materials.	European Commission (2022)
Compostable	Compostable plastics are a subset of biodegradable ones and typically decompose in industrial composting facilities, and first need to be collected. Compostable plastics may be made from biological resources or fossil raw materials.	European Commission (2022)

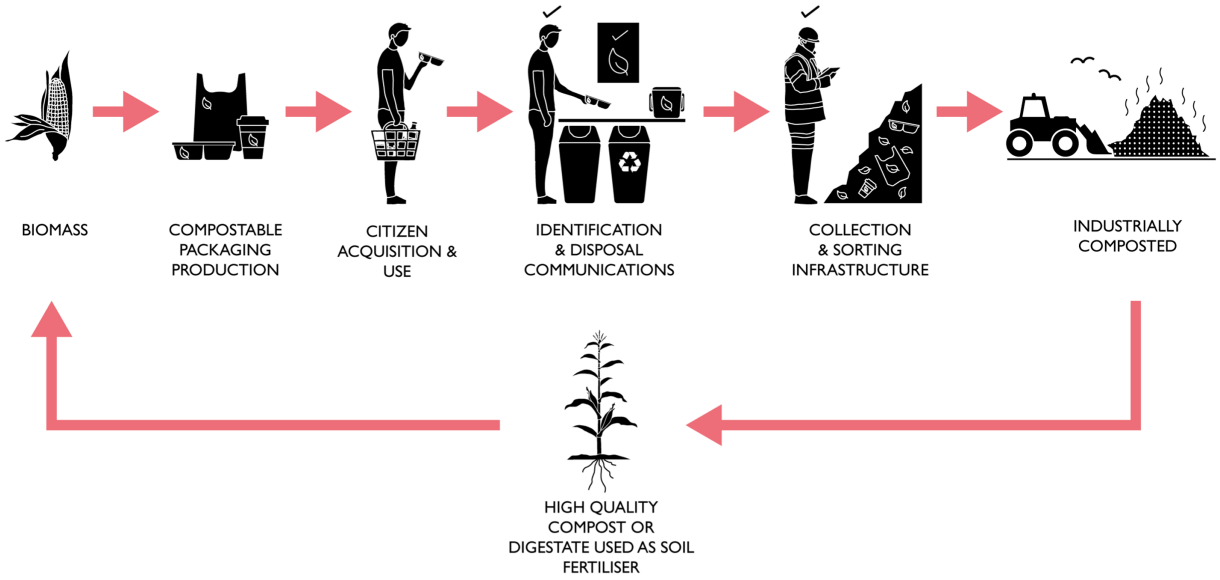

FIGURE 1
Circular economy of compostable plastics. Source: Allison et al. (2022).

An intervention aimed at promoting the correct disposal of compostable plastics within a UK implementation context has been developed but has yet to be evaluated for effectiveness in changing behaviour (Allison et al., 2022). This intervention consists of disposal instruction labels aimed at addressing one of the key barriers to correct disposal—not knowing which bin is the correct one for disposal. Readers are referred to this paper for further detail on the rationale and processes involved in the design of these disposal instruction labels. The disposal instructions are illustrated in this paper in section 2.3.1.1 Disposal instruction labels. The present study aimed to evaluate the impact of disposal instruction labels on the disposal of a range of different compostable plastic packaging formats.

At the time of this study in 2023, the UK Government was consulting on new mandatory labelling for packaging as part of the Extended Producer Responsibility Scheme reforms (DEFRA, 2020). Mandatory labelling aims to provide citizens with clear, binary instructions on what can and cannot be recycled: "recycle" or "do not recycle" (DEFRA, 2020). As compostable plastics are not deemed "recyclable" (as they are not designed to be mechanically recycled but to break down in specific composting conditions), the current plan is to label these, from 2024 onwards with "do not recycle" so they are disposed of with general waste (DEFRA, 2022). Most compostable plastic materials (e.g., PLA used in food packaging) would not degrade outside of an industrial compost facility as they have different material properties and requirements for processing compared to traditional fossil-based recyclable plastics (e.g., PET commonly used in single-use plastic water bottles) (Ruggero et al., 2019; Purkiss et al., 2022; Plastic Pollution Coalition, 2023). This binary mandatory labelling policy is significant because, from 2024 onwards, the UK government also aims to roll out nationwide food waste collection services. There are concerns that food waste collection services may become overwhelmed with large volumes of compostable plastic packaging waste that are not currently able to be processed by the majority of UK waste processing facilities. While there is an understanding amongst government and industry that collecting and processing these materials via food waste is likely to be the desired end-point (WRAP, 2021), this is an anticipated future scenario once other aspects of the compostable plastics system improve (see Figure 1).

Mandating the use of "do not recycle" to direct compostable plastics to general waste raises questions about behaviour change. To enable correct practices, it is necessary to gather information about what UK citizens are currently doing with compostable plastics without government-mandated disposal instruction labels. This would form a baseline for evaluating the impact of the disposal instruction "do not recycle". As "recycle"/"do not recycle" is a binary messaging system that was designed for a two-bin scenario (recycling and general waste), it is empirically unknown how effective "do not recycle" will be once there are three mainstream options for the disposal of waste (recycling, general waste, and food waste). It is unclear how obvious the general waste bin will be as the disposal option for compostable plastics.

To prepare for an ideal future scenario where compostable plastics are disposed of with food waste (so they can be composted), the UK industry and government are discussing the potential implementation of a new disposal instruction logo indicating "compostability". However, the UK government have been clear that this would only be used to label compostable plastics in the instance that there is a strong, evidence-based case for this scenario. For example, this will require sound evidence that there is adequate infrastructure in place to appropriately manage compostable plastics and evidence that compostable plastics provide ecological or agricultural benefits to soils or digestate when properly broken down (DEFRA, 2022). Therefore, there is also a need to understand which types of logos and disposal instructions might be most effective to denote the disposal of compostable waste with food waste to support policy decision-making in this area. To this end, the current study has four research questions:

1 In a three-bin scenario (food waste, general waste, and recycling), which bin do citizens put various types of compostable plastic packaging in when there is no disposal instruction?
2 In a three-bin scenario (food waste, general waste, and recycling), is "do not recycle" an effective disposal instruction

for getting citizens to dispose of compostable plastic waste with general waste?

3 In a three-bin scenario (food waste, general waste, and recycling), which disposal instruction ("compost", "compost with food waste", "put with food waste", and "recycle with food waste") is most effective at getting citizens to put compostable plastic packaging with food waste?

4 Which potential alternative disposal instruction logos do citizens prefer for compostable packaging and why?

2 Materials and methods

All materials for this study including raw data and analysis code are available openly via Open Science Framework (OSF).[1]

2.1 Participants

Study participants were members of the UK public ($n = 1{,}008$). They had to be over 18, normally resident in the UK for the last 12 months, and have sufficient English to complete the study. Participants were recruited via Prolific.co (n.d.) and advertising the study through email to the mailing list of The Big Compost Experiment (2020) citizen science project. Participants recruited via Prolific were compensated for their time at a rate of £10.23/h. Prolific ensures a representative sample in terms of gender, age, and ethnicity for UK participants. Participants recruited via the Big Compost Experiment took part voluntarily.

2.2 Design

This study had a mixed-methods design. It consisted of an experiment and a questionnaire.

The experiment had a mixed 6×11 factorial experimental design. There were two independent variables. One was between participants: disposal instruction, on six levels (control, do not recycle, compost, recycle with food waste, compost with food waste, and put with food waste). Disposal instruction was operationalised as the wording on the disposal instruction label presented to participants. Participants were randomly allocated to either one of the six disposal instruction conditions, one of which included a control condition consisting of no disposal instruction.

The other independent variable was within participants: packaging format, on 11 levels (sachet, bag, clamshell, container, plastic cup, food sticker, hot drink cup, coffee packaging, sandwich packaging, tea packaging, and ready meal tray). The packaging format was operationalised as the type of compostable plastic packaging the disposal instruction labels was tested on.

The study had one binary dependent variable: disposal behaviour (correct vs. incorrect) which was operationalised as whether or not participants disposed of the packaging in the desired bin during a given trial. To complete a trial correctly, all items had to be disposed of in the right bin. In the case of multi-material packaging, all parts had to be disposed of correctly; e.g., in the case of the tea package consisting of a box and compostable teabag, the participant had to sort the box correctly (i.e., in the recycling bin) and the teabag correctly (i.e., in the food waste bin or general waste bin depending on the analysis scenario) to get a correct score for that trial.

The questionnaire consisted of an online cross-sectional survey of close-ended and open-ended questions.

2.3 Materials

2.3.1 Experimental stimuli

2.3.1.1 Disposal instruction labels

The rationale for the disposal instructions labels has been justified in a previous publication (Allison et al., 2022). The final version of the wording and logo used in the disposal instruction labels is depicted in Figure 2.

2.3.1.2 Compostable packaging formats

The disposal instruction labels were superimposed onto images taken of 11 compostable plastic packaging formats (see Table 2). The authors recognise that different aspects of packaging labelling and communication design (words, logos, pictures, colour, and material choice) have varying influences on citizen behaviour and that disposal instruction labels are one aspect of a larger complex system of communication (WRAP, 2021). These items were selected as they are available in high street shops in the UK, marketed as compostable, and made from compostable materials (e.g., PLA, PBAT, and corn starch).

2.3.1.3 Distractor packaging formats

Distractor stimuli were also used and consisted of images taken of common general waste and dry recycling items, e.g., juice cartons and chocolate wrappers (see Table 2). The disposal instruction labels that were superimposed onto the distractor items consisted of the disposal instruction "recycle" for recyclable items and "do not recycle" for general waste items, with the same OPRL Recycle Now logo, as this is the current UK system for labelling this type of waste, at the time of this study (OPRL, n.d). In the control condition, the distractor waste items had no disposal instruction label.

2.3.2 Questionnaire

2.3.2.1 Hypothetical disposal instruction logo for compostable waste

Introduced in a previous publication (Allison et al., 2022), Appendix A in OSF[2] details the set of 15 hypothetical disposal instruction logos that were developed in collaboration with a designer at the UCL Plastic Waste Innovation Hub (DP) and industry, policy, and academic stakeholders. They were developed using associative graphic imagery commonly used in UK waste disposal infrastructure

1 https://osf.io/vj9hy/

2 https://osf.io/xg73u/

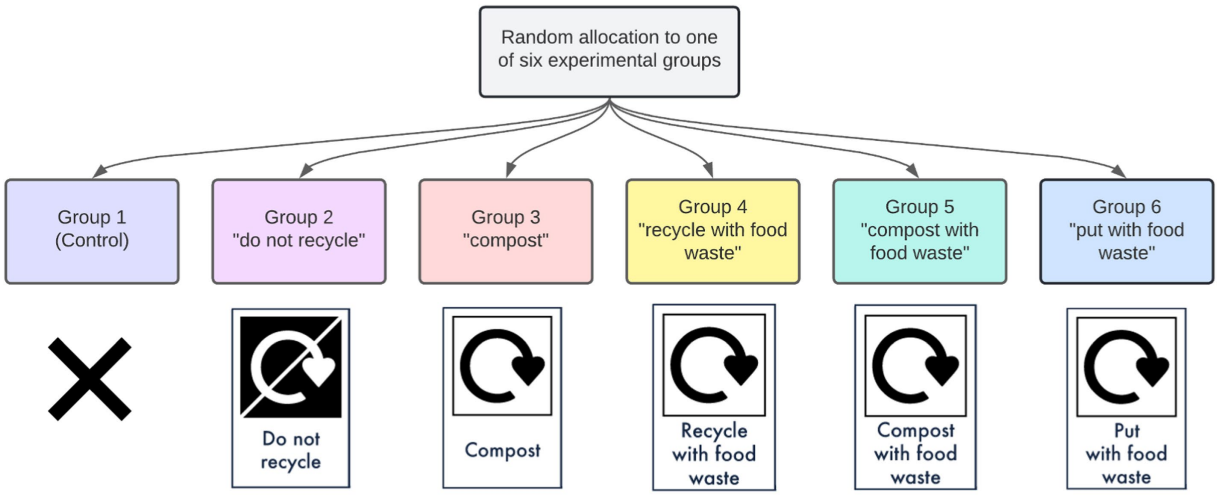

FIGURE 2
Disposal instruction labels used for compostable plastic packaging.

and communications, such as an image of a "leaf", "seedling", "apple core", "chasing arrows recycling symbol", and WRAP's "chasing heart" logo.

Participants were asked to select their preferred logo, provide a reason for their preference ("Please provide a reason for your answer"), and provide their thoughts on a potentially better disposal instruction logo for compostable packaging waste ("If you think there could be a better disposal instruction label for compostable packaging than the ones we have shown you, could you please share your thoughts with us?").

2.3.2.2 Britain talks climate toolkit

The Britain Talks Climate citizen engagement toolkit's "Golden Questions" were used to collect psychological demographics (Wang et al., 2020). Based on how participants respond to the toolkit's 16 questions, the tool "segments" respondents into one of seven possible "psychological" groups (see Appendix B in OSF: https://osf.io/9p4kx).

2.4 Procedure

Ethical approval for the study was received from UCL (project ID: CEHP/2020/579, data protection: Z6364106/2022/03/63). The study was built on Gorilla (Anwyl-Irvine et al., 2020) and piloted with a sample of university staff and students before data collection for usability and accessibility. Participants accessed the study via an online web link, which took approximately 10 min to complete. Informed consent was obtained before any data collection. Data collection occurred between the 14th and 28th of November 2022.

Participants completed 16 trials in total. Each trial consisted of sorting stimuli into one of three bins: food waste, recycling, or general waste (if the packaging had multiple parts, each part had to be sorted separately). An example is shown in Figure 3. Eleven trials consisted of sorting compostable packaging formats. Five trials consisted of sorting distractor packaging formats. The order of trials was counterbalanced to minimise order effects (Krosnick and Alwin, 1987). Participants subsequently completed a survey answering questions about their demographics and logo preferences.

2.5 Data analysis

Data were prepared for analysis in Microsoft Excel and analysed using Microsoft Excel and RStudio (RStudio Team, 2020).

To answer Research Question 1, all compostable plastic packaging components were analysed in isolation and not as part of a wider packaging format, e.g., just the teabag, not the box. Frequencies were used to summarise findings. Inferential statistics were run to answer Research Question 2 and Research Question 3. The data analytic approaches for these two research questions are detailed in the subsequent sections. To answer Research Question 4, percentages were used to summarise logo preferences. Thematic analyses (Braun and Clarke, 2006) were conducted on open-ended responses exploring reasons for preference and ideas for a better logo.

2.5.1 Building the models for research question 2 and research question 3

R Packages "lme4" (Bates et al., 2009) and "lmertest" (Kuznetsova et al., 2015) were used for the main tests and "emmeans" (Lenth et al., 2019) for follow-up tests. Two separate generalised linear mixed-effects models were run to see whether disposal instructions predicted correct disposal. To account for the repeated-measures methodology (all participants disposed of each packaging format), a by-participant random intercept was added. The same control group was used for the analyses concerning Research Question 2 and Research Question 3. In the former, the control group results were based on the data coded as the *general waste bin* being the correct bin. In the latter, the control group results were based on the data coded as the *food waste bin* being the correct bin.

2.5.1.1 Control variables

To assess for any control variables, the relationship between the socioeconomic (i.e., age, gender, income, and education), psychological (i.e., ideological orientation), and behavioural (i.e., home-composting and food waste recycling status) demographic variables and the dependent variable (i.e., correct disposal) was explored via two different approaches: (a) separate generalised linear mixed-effects models per variable and (b) one generalised linear mixed-effects model with all control variables

TABLE 2 Table showing the images of the packaging formats used in trials.

Compostable items	Sachet	Bag	Clamshell	Container	Cup	Food sticker	Hot drink container (cup and lid)	Coffee (box and pod)	Sandwich (box and film)	Ready meal (sleeve, tray, and film)	Tea (box and teabag)
											
Distractor items	Chocolate wrapper (General waste)			Plastic milk bottle (Recycling)		Juice carton (Recycling)		Glass jar (Recycling)		Aluminium can (Recycling)	
											

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FIGURE 3
Example trials from the "compost" disposal instruction condition. The image on the left depicts an example of what participants saw when sorting an item of mono-material packaging, whereas the image on the right depicts an example of what participants saw when sorting an item of multi-material packaging.

included. The control variables were introduced as predictors of correct disposal, with a by-participant random intercept, following the structure of the main models. Variables found to be significant at $p<0.05$ across both approaches were entered into the main models. If the main models failed to converge, the control variables were removed on the basis that it is not necessarily the "maximal", but a more parsimonious model, with a random effects structure, that may be most suitable for describing the data in factorial experiments with repeated-measures aspects (Matuschek et al., 2017; Seedorff et al., 2019). Details of the control variable analyses can be found in Appendix C in OSF.[3]

2.5.2 In a three-bin scenario, is "do not recycle" an effective disposal instruction for getting citizens to dispose of compostable plastic waste with general waste? (Research question 2)

The first independent variable in the model was the disposal instruction, operationalised as either the control or the "do not recycle" disposal instruction. The second independent variable was the packaging format. An interaction term was included to assess whether the effectiveness of "do not recycle" as a disposal instruction varied according to packaging format. The dependent variable was binary (correct vs. incorrect disposal). Correct disposal was operationalised as the disposal of compostable plastic packaging items with *general waste*. Incorrect disposal was operationalised as disposal with food waste or recycling. The final model (Conditional $R^2 = 57.5\%$) had the following structure:[4]

$$\text{disposal} \sim \text{experimental\_group}^{*}\ \text{packaging\_format} + (1 \mid \text{participant\_id})$$

2.5.3 In a three-bin scenario, which disposal instruction is most effective at getting citizens to put compostable plastic packaging with food waste? (Research question 3)

The first independent variable in the model run was the disposal instruction operationalised as either the control, "recycle with food waste", "compost", "compost with food waste", or "put with food waste" disposal instructions. The second independent variable was the packaging format. Correct disposal was operationalised as the disposal of compostable plastic packaging items with *food waste*. Incorrect disposal was operationalised as disposal with general waste or recycling. Disposal rates across the different conditions were compared against each other. The control variables *home composting status* and *food waste recycling status* were significantly associated with disposal rates and so were included in the final analysis.[5]

An interaction term was initially included to assess whether the effectiveness of the disposal instructions varied according to the packaging format. However, the model did not converge, likely because the interaction term led to the estimation of more than 5×11 parameters. To simplify the model, the random intercept was prioritised over the interaction between the fixed effects in line with

3 https://osf.io/vjmne

4 The control variable *income* was initially included in the main model; this was the only control variable significantly associated with disposal rates. However, the main model did not converge when *income* was included and so was removed.

5 *Age* was also significant so initially included in the model but the model did not converge. As this was the variable with the lowest estimate, it was omitted from the analysis to reduce complexity as per guidance (Seedorff et al., 2019; Matuschek et al., 2021).

guidance (Sonderegger, 2023) and given how much variance the random-effect structure explained (marginal $R^2 = 38\%$; conditional $R^2 = 62\%$). The final model had the following structure:

$$\text{disposal} \sim \text{experimental\_group} + \text{packaging\_format} + \text{home\_composting\_status} + \text{food\_recycling\_status} + (1 \mid \text{participant\_id})$$

3 Results

3.1 Participant characteristics

Participant characteristics are summarised in Table 3. The majority identified as women (55%) followed by men (43.8%) and with a small percentage as non-binary (0.6%) or preferring not to disclose their gender (0.6%). The mean age of participants was 53.57 (SD = 16.59) with most either educated to undergraduate (37.1%) or master's level (22%). This indicates an older (ONS, 2022) and more educated (OECD, 2023) sample than UK averages. The majority of survey participants had annual household incomes less than £45,000, aligning with national figures (ONS, 2020).

The majority of participants were classified as "Progressive activists" (39.5%) and "Established liberals" (21.6%) which is considerably higher than the UK averages of 13 and 12%, respectively (Wang et al., 2020). The third most populous segment was "Civic pragmatists" (16.1%), which is closer to the UK average of 13% (Wang et al., 2020).

About half of the participants (53.67%) indicated that they were being provided with a local food waste collection service. This mirrors UK statistics for household food waste collection services with about half of households offering such services (DEFRA, 2017). Almost all participants recycled dry recyclables (97.62%). About half engaged in home-composting (53.57%), which is likely to be much higher than national averages, and other studies suggest that only about a third of households in England with a garden home-compost (Eades et al., 2020). The question asking the likelihood of engaging with local food waste collection services if provided with free compostable liners was explored in more depth by asking participants to provide a reason for their answer. This supplementary analysis, including directions to the raw data and codebook, can be found in Appendix D in OSF.[6]

3.2 General descriptive statistics

Appendix E in OSF[7] summarises the percentage of correct disposal of recyclable and general waste items used as distractor stimuli. Appendix F in OSF[8] depicts the overall count data across all conditions, i.e., the frequency of disposal, into each bin, per disposal instruction for each item of mono-material and multi-material packaging, respectively.

3.3 Which bin do citizens put various types of compostable plastic packaging in when there is no disposal instruction label? (Research question 1)

Appendix G in OSF[9] summarises the frequencies with which each item of compostable plastic packaging was disposed of in each bin when there was no disposal instruction (i.e., the control condition). The packaging parts that were most likely to go in general waste were as follows: sachet, food sticker, coffee pod, sandwich film, and ready meal film. Packaging parts that were most likely to go in food waste were as follows: bag and teabag. Packaging parts that were most likely to go in recycling were as follows: clamshell, container, plastic cup, hot drink cup, hot drink lid, and ready meal tray.

3.4 Is "do not recycle" an effective disposal instruction for getting citizens to dispose of compostable plastic waste with general waste? (Research question 2)

Appendix H in OSF[10] summarises the rates of correct disposal rate for each packaging format (i.e., the percentage of participants putting that item in general waste vs. food waste or recycling). Results showed that when the label reads "do not recycle", participants were, overall, 11.15% more likely to correctly dispose of the packaging in the general waste bin (OR = 0.09, 95% CI [0.08, 0.10], $p < 0.0001$). *Post-hoc* analyses revealed that this effect was evident for seven packaging formats – all but the sachet, the food sticker, the sandwich, and the tea (see Table 4).

In a three-bin scenario, "do not recycle", overall, significantly increased participants' disposal of compostable plastic packaging with general waste when compared with controls with no disposal instruction. However, this effect was coming from certain packaging formats: the sachet, bag, clamshell, container, cup, hot drink container, coffee, sandwich, and ready meal. It was not coming from the tea, sachet, sandwich, or food sticker packaging formats for which the difference in disposal rate was not statistically significant.

3.5 Which disposal instruction is most effective at getting citizens to put compostable plastic packaging with food waste? (Research question 3)

Appendix I in OSF[11] summarises the rates of correct disposal for each packaging format (i.e., percentage of participants putting that item in food waste vs. general waste or recycling). Across all conditions, the two packaging formats with the highest rate of correct disposal in the food waste bin were the tea and bag packaging formats. Food waste recycling status was not significantly

6 https://osf.io/jvfyk
7 https://osf.io/5mquj
8 https://osf.io/jm35y
9 https://osf.io/pn7re
10 https://osf.io/j8wm3
11 https://osf.io/vk5a7

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TABLE 3 Participant characteristics.

Characteristics	*N* (missing)	%	Mean (SD)
Gender	1,008 (0)		
Men	442	43.8	
Women	554	55	
Non-binary	6	0.6	
Prefer not to say	6	0.6	
Age (years)	988 (20)		53.57 (16.59)
Highest level of education	1,008 (0)		
Primary education	2	0.2	
Lower secondary education	36	3.6	
Higher secondary education	146	14.5	
Vocational certificate	105	10.4	
Associate degree	48	4.8	
Undergraduate degree	374	37.1	
Postgraduate masters	222	22.0	
Postgraduate doctorate	75	7.4	
Ideological demographic	1,008 (0)		
Progressive activist	401	39.5	
Civic pragmatists	163	16.1	
Disengaged battlers	54	5.3	
Established liberals	219	21.6	
Loyal nationalists	63	6.2	
Disengaged traditionalists	35	3.5	
Backbone conservatives	79	7.8	
Annual household income pre-taxes	1,008 (0)		
Less than £10,000	62	6.2	
£10,000 to £19,999	109	10.8	
£20,000 to £29,999	177	17.6	
£30,000 to £39,999	136	13.5	
£40,000 to £49,999	115	11.4	
£50,000 to £59,999	96	9.5	
£60,000 to £69,999	48	4.8	
£70,000 to £79,999	52	5.2	
£80,000 to £89,999	36	3.6	
£90,000 to £99,999	24	2.4	
£100,000 to £149,999	52	5.2	
£150,000 or more	12	1.2	
Prefer not to say	89	8.8	
Recruitment method	1,008(0)		
Prolific	600	59.5	
Big Compost Experiment mailing list	408	40.5	
Access to local food waste collection services at primary residence	1,008 (0)		
Yes	541	53.67	
No	413	40.97	
Unsure	54	5.35	

(Continued)

TABLE 3 (Continued)

Characteristics	*N* (missing)	%	Mean (SD)
If YES, currently separates food waste from other waste for local waste collection	541 (0)		
Yes	470	86.88	
No	71	13.12	
If YES, frequency of food waste recycling	470 (0)		
Never	0	0	
Almost never	1	0.21	
About half of the time	18	3.83	
Most of the time	119	25.32	
Always	331	70.43	
Access to an outdoor space at primary residence (e.g., garden and terrace)	1,008 (0)		
Yes	952	94.44	
No	56	5.56	
Currently engages in home-composting	1,008 (0)		
Yes	540	53.57	
No	468	46.43	
Currently recycles dry recyclables (e.g., plastic, glass, metal, cardboard, and paper)	1,008 (0)		
Yes	984	97.62	
No	24	2.38	
If YES, the frequency of dry recycling	984 (0)		
Never	0	0	
Almost never	0	0	
About half of the time	15	1.52	
Most of the time	172	17.48	
Always	797	81.00	
Likelihood of engaging with local food waste collection services if provided with free compostable liners by local authority	1,008 (0)		
Yes	599	59.42	
No	277	27.48	
Unsure	132	13.10	

associated with disposal rates in the food waste bin (OR = 0.16, 95% CI [0.12, 1.28], $p = 0.20$); however, home-composting status was (OR = −0.30, 95% CI [−0.42, −0.18], $p = 0.01$). The odds of correctly disposing of food waste were higher amongst those who did not engage in home composting.

Results showed that, in a three-bin scenario, "compost with food waste" had the highest rate of correct disposal in the food waste bin when compared to the control group with no disposal instruction. However, it was not statistically different from "put with food waste" or "recycle with food waste". All three disposal instructions led to statistically similar disposal rates in the food waste bin. "Compost with food waste", "put with food waste", and "recycle with food waste" were all significantly better at promoting the disposal of compostable plastic packaging in the food waste bin when compared with "compost". These results can be seen in Table 5.

3.6 Which potential alternative disposal instruction logos do citizens prefer for compostable packaging and why? (Research question 4)

Logo preferences are shown in Appendix J in OSF.[12] Thematic findings for the top two logos are summarised in this paper, i.e., Logo 15 (49.8%) and Logo 5 (24.58%). The full detailed thematic analyses for the top five logos (>5% preference) are openly available via OSF.[13]

12 https://osf.io/px4d3

13 https://osf.io/7xnv6

TABLE 4 *Post-hoc* comparisons for correct disposal of each packaging format in the general waste bin between the control and "do not recycle" conditions.

Packaging format	OR	SE	*p*
Sachet	0.47	0.21	0.986
Bag	**0.24****	0.07	**<0.001**
Clamshell	**0.04****	0.001	**<0.001**
Container	**0.01****	0.004	**<0.001**
Cup	**0.02****	0.007	**<0.001**
Food sticker	0.46	0.21	0.92
Hot drink container (cup and lid)	**0.19****	0.07	**0.001**
Coffee (box and pod)	**0.19****	0.07	**<0.001**
Sandwich (box and film)	0.33	0.12	0.244
Ready meal (tray, sleeve, and film)	**0.02****	0.006	**<0.001**
Tea (box and bag)	0.49	0.14	0.56

**, *p*-value is statistically significant at <0.001. OR = odds ratio. OR < 1 means that the control group was less likely to dispose of the packaging in the general waste bin. Bold values are highlighting statistically significant.

TABLE 5 Comparisons of correct disposal between disposal instruction labels designed to denote disposal of compostable plastic packaging with food waste.

Disposal instruction	OR	SE	*p*
Compost/Control	12.82	2.4	**<0.001****
Compost with food waste/Control	34.01	6.46	**<0.001****
Control/Put with food waste	0.33	0.006	**<0.001****
Control/Recycle with food waste	0.04	0.008	**<0.001****
Compost/Compost with food waste	0.38	0.07	**<0.001****
Compost/Put with food waste	0.42	0.08	**<0.001****
Compost/Recycle with food waste	0.53	0.1	**0.005***
Compost with food waste/Put with food waste	1.12	0.21	0.971
Compost with food waste/Recycle with food waste	1.4	0.26	0.361
Put with food waste/Recycle with food waste	1.25	0.23	0.742

**, *p*-value is statistically significant at <0.001; *, *p*-value is statistically significant at <0.0. Bold values are highlighting statistically significant.

Participants selected their preferred logo on the basis that it was the clearest to understand. However, there was variation between logos in terms of why it was perceived this way (see Table 6). Logo 15 was valued for its inclusion of a range of organic waste materials, instructive imagery, and avoidance of associative symbols. Logo 5 was valued for its use of associative symbols, which were deemed intuitive and logical. Nonetheless, across both logos, participants felt that a logo alone would be insufficient as a disposal instruction strategy and emphasised the importance of written disposal instructions to reduce any potential confusion. Participants' ideas for a better logo can be found in Appendix K in OSF.[14]

4 Discussion

We discuss the results according to each research question followed by the implications of the study findings for policy and practice. Study strengths, limitations, and avenues for future research are then considered.

4.1 Which bin do citizens put various types of compostable plastic packaging in when there is no disposal instruction? (Research question 1)

Results show that with no disposal instruction label, the correct disposal of these items is not obvious from their appearance. Items that "look" like dry recyclable waste were put in the recycling bin (i.e., similar appearance to traditional dry recyclable plastics like PET), those that "look" like general waste were put in general waste (i.e., similar appearance to non-recyclable plastic like and semi-flexible or plastic-coated materials), and those that have a familiar status as being compostable went in food waste (i.e., the bag and teabag).

These findings align with Ansink et al. (2022) and Taufik et al. (2020) where citizens incorrectly disposed of compostable plastic cups and water bottles into the recycling bin, even those labelled with

14 https://osf.io/xczdt

TABLE 6 Thematic analysis on reasons for logo preferences.

Logo 15		
	Inclusive	• The logo depicts a variety of organic waste items, indicating that the food waste bin is designed for multiple types of organic waste. • The depicted items include unusual items (e.g., fish bones). • Symbols clearly indicate what can be put in food waste.
	Instructive	• The variety of food waste depicted shows that the item bearing the logo should be disposed of with other food waste items. • Thanks to the arrow, the food waste bin is marked as the clear destination for items with this logo.
	Direct & recognisable	• Avoids symbolism (like variations of the Chasing Arrows recycling logo) and just uses recognisable food waste and a recognisable bin.
	Room for improvement	• The imagery could be confused with general waste if that's where people discard their food waste currently. • Unlikely to be sufficient as a strategy without the inclusion of written disposal instructions.
Logo 5		
	Associative linking of familiar symbols	• Apple core is a good symbol to relate the logo to the food waste concept. • Chasing Arrows is a well-known recycling symbol and so linking an established waste management process (recycling) to a less familiar process (composting).
	Appropriate presentation & adaptation	• Placing these two symbols together logically links the recycling concept to the food waste concept. • Adapting dry recycling logic to biodegradation.
	Room for improvement	• The imagery could be confused with traditional dry recycling as entirely associative. • Unlikely to be sufficient as a strategy without the inclusion of written disposal instructions.

messaging designed to communicate disposal instructions. The authors speculated that these patterns are likely to be due to a habitual association between these packaging formats and the recycling bin—it is difficult to "snap" citizens out of their default waste management patterns. In the present study, the teabag and compostable shopping bags may have been less likely to trigger an automatic response with the recycling bin as they do not "look" like traditionally recyclable waste, unlike the plastic water bottles and cups in the Ansink et al. (2022) and Taufik et al. (2020) studies. It is also likely that the UK public's familiarity with the compostability of teabags and the particular brand of shopping bag used in this study led to them being more likely to put them in food waste.

4.2 Is "do not recycle" an effective disposal instruction for getting citizens to dispose of compostable plastic waste with general waste? (Research question 2)

The label "do not recycle", overall, significantly increased the rate of correct disposal of general waste. However, *post-hoc* analyses revealed that this effect was coming from the bag, clamshell, container, cup, hot drink container (cup and lid), coffee (box and pod), and ready meal (sleeve, tray, and film), not the tea (teabag and box), sandwich (box and film), and sachet or food sticker. The significant effect of "do not recycle" appears to be mostly due to packaging that "looks" like dry recyclate being re-directed to general waste. As the packaging that "looks" like general waste already had high disposal rates with general waste in the control, "do not recycle" only increased that figure from what was already quite high to even higher. In the case of the sachet, sandwich, and food sticker, the increase was not high enough to reach statistical significance as disposal rates into general waste were already very high in the comparison group. It is impossible that "ceiling effects" were occurring. This is when the scores of research participants are clustered near the best possible score (i.e., the "ceiling"; in this case, 100% correct disposal) and so the measure (the disposal instruction) loses value.

The *post-hoc* analyses showed that "do not recycle" did not significantly increase the rate of correct disposal for the tea (teabag and box). While the correct disposal of compostable shopping bags did increase significantly, the rate was still low in comparison with the other packaging formats; correct disposal was only increased to 50%. An explanation for this could be that for items that "look" recyclable or like general waste, the food waste bin was not a plausible option. It is likely less intuitive to dispose of something that does not "look" organic with food waste than to dispose of something that "looks" recyclable or organic with general waste. For items that have entered the mainstream UK public consciousness as being compostable (e.g., teabags and compostable shopping bags), "do not recycle" may not indicate a clear enough disposal instruction in a three-bin system and so disposal decisions are being split between the food waste bin (because that is the intuitive option) and general waste bin (because that is what this instruction has been used to denote in the past).

These findings suggest that "do not recycle" may be effective for diverting some types of waste when there are three bins to choose from but not for waste items that have an association with compostability. For items associated with compostability, "do not recycle" may not provide the clear and direct instruction that seems to be a running theme in terms of what citizens desire in a disposal instruction label. An avenue for future research could be to investigate whether a direct positive command, e.g., "dispose of with general waste", would perform better at increasing rates of compostable plastic packaging with general waste.

4.3 Which disposal instruction is most effective at getting citizens to put compostable plastic packaging with food waste? (Research question 3)

To promote the disposal of food waste, "compost with food waste" had the highest rate of correct disposal in the food waste bin when compared to no disposal instruction. However, there was no difference between the three types of disposal instruction. This suggests that explicitly mentioning "food waste" is important as "compost" alone was not as effective as "compost with food waste", "put with food waste", or "recycle with food waste".

These findings support and extend prior research. There is a growing body of evidence showing citizens' desire for clear, specific, and directive disposal instructions to enable the correct waste management behaviours (Langley et al., 2011; WRAP, 2021). This study provides supporting experimental evidence; clear, directive disposal instructions are not only desired by citizens but also promote the disposal of compostable plastics in the instructed manner.

Engagement in home composting was, overall, associated with reduced rates of correct disposal of packaging with food waste. A possible explanation for this is that many of the home composters may have been participants of the Big Compost Experiment citizen science project as the mailing list of this project was used to recruit participants. A key finding from this citizen science project was that much of the compostable plastic packaging on the UK market does not break down efficiently in most home composts (Purkiss et al., 2022). A possible reason is that compostable materials require specific, controlled conditions to biodegrade effectively, which can be difficult to maintain given the variability of home composting methods and conditions (e.g., Arrigoni et al., 2018). It is therefore plausible that home-composting participants disposed of these types of packaging in the general waste bin instead of the food waste bin as they did not trust the disposal instructions. As home composting is a niche practice in the UK (Eades et al., 2020), the impact of this on the wider population in terms of a broader waste management strategy is likely to be minimal.

4.4 Which potential alternative disposal instruction logos do citizens prefer for compostable packaging and why? (Research question 4)

The logo that participants had the strongest preference for a simple, direct, comprehensive, and explicit in denoting disposal in the food waste bin. The second preference was for a logo based on adaptations of the more established "chasing arrows" recycling logo. Some thought that an instructive logo was easier to understand, whereas others thought that a logo they associated with recycling was easier to understand.

Most logos denoting compostability make use of associative symbols, e.g., the European Bioplastics "seedling" logo. Nonetheless, symbols only have meaning within a context as they are something that represents or stands for something else. In the case of the European Bioplastics seedling logo, the logo represents adherence to compostability standards set by independent certifiers (e.g., TÜV Austria and DEN CERTCO) (European Bioplastics, 2019). In addition, there are highly efficient organic waste collection systems across Europe, including Austria, Slovenia, Belgium, and Germany where the bio-waste capture rate is over 60% (this figure represents the percentage of food waste collected as a percentage of food waste generated) (Brusselaers and Van Der Linden, 2020). Their success can be attributed to infrastructure, including simple-to-use, nationally uniform and reliable waste collection and processing services but also to high citizen engagement, which has been achieved through behaviour change interventions, including effective educational and motivational communications (Favoino and Giavini, 2020). The European Bioplastics seedling logo is therefore emblematic of a collectively understood and agreed upon something else. The more instructive logos were likely preferred in a UK context given the wide-scale citizen confusion about these materials and the wider system failures outlined earlier. In a UK context, there is yet to be a functional and collectively established something else for which an associative symbol could be emblematic of meaningfully.

Another reason for the differences in preferences could be that those who are generally more acquainted with and involved in waste management (e.g., those who home compost, already recycle food waste or who are generally pro-environmentally oriented) are more knowledgeable and so prefer associative recycling logic, whereas less knowledgeable citizens are more likely to prefer a direct and instructive logo. This is difficult to ascertain as the thematic findings were not linked to survey respondents' home composting status, recycling status, or ideological orientation. Overall, the findings suggest that a more direct and instructive logo is likely the preferable choice if the goal is to maximise general public engagement. This is corroborated by the quantitative results; clear, instructive messaging was most effective for all.

4.5 Implications

The findings have implications for government policies and industry practices around labelling of compostable plastics. To direct items into food waste, explicitly mentioning food waste in a disposal instruction is likely to be effective. To direct items to general waste, "do not recycle" might work for some packaging formats, but it is likely that a clearer, directive disposal instruction; e.g. "dispose of with general waste" may be more effective. Evidence from WRAP (The Waste and Resources Action Programme; a climate action NGO and British charity dedicated to working with businesses, individuals and communities to achieve a circular economy) corroborates this; citizens have a clear preference for labels which are directive, telling them exactly what to do with waste (WRAP, 2021). If a separate compostability logo comes into practice, it will be important for this to be as direct, explicit, and comprehensive as possible. While symbolic and associative logos may be liked, for example, those based on adaptations of the more established "chasing arrows" recycling logo, these types of logos may be more aesthetically pleasing than they are instigators of behaviour change.

The study findings also have wider implications for product and packaging design. The findings from the control group with no disposal instructions show that citizens struggle to identify compostable plastic packaging based on appearance alone. Other studies support that distinguishing these materials from their appearance is challenging (Herbes et al., 2020; Taufik et al., 2020). A recent study by the US-based Composting Consortium and

Biodegradable Products Institute (BPI) shows that there was an increase in US citizens' identification of a range of compostable plastic packaging formats based on varying uses of colour (Composting Consortium, 2023). It may therefore be useful to ensure compostable plastic packaging is as distinct as possible to enable their identification and promote their correct sorting for disposal. This could look like using material textures and colours that are not associated with the look and feel of recyclable waste.

4.6 Strength, limitations, and future research

A strength of this study is the testing of a range of different compostable plastic packaging formats. Prior experiments have relied on testing a single packaging format (e.g., plastic water bottles or plastic cups) (Taufik et al., 2020; Ansink et al., 2022). Testing a wider range of packaging formats minimises the potential confounding effects of participants' existing behavioural associations with a type of packaging.

The study method presents some issues with ecological validity as it does not accurately simulate the real-world disposal environment, meaning that the effectiveness of the disposal instructions may be overestimated. The stimuli were maximised on screen and participants concentrated on a science experiment. In reality, people often do not look at or notice labels on packaging, as disposal behaviour is shown to be highly habitual and automatic (Taufik et al., 2020; Ansink et al., 2022). Even if the ideal wording and logo for compostable packaging were identified, people need to engage with them in the first instance.

Natural experiments or other types of in-person user experience studies where people physically interact with packaging can overcome some of these limitations and improve confidence in the generalisability of findings. Testing potential interaction effects between other packaging attributes on disposal behaviour can also extend findings as they have been found to influence disposal decisions, e.g., the feel of the materials used for packaging, placement of information on packaging (Nemat et al., 2020), the degree of distortion of packaging (Baxter et al., 2016; Trudel et al., 2016), or the degree to which the packaging is wet or contaminated (Langley et al., 2011).

Future research is required to confirm whether other, clearer disposal instructions might be better for diverting compostable plastic packaging to general waste. Based on the study findings, we speculate that a positive direct command; e.g., "dispose of with general waste" may be a better disposal instruction when compared to the negative command "do not recycle", especially for more ambiguous packaging formats or those that look organic. The present experimental paradigm could be adapted to investigate this.

5 Conclusion

This study aimed to evaluate disposal instruction labels for their effectiveness in promoting the desired disposal of compostable plastic packaging. With no disposal instructions, citizens disposed of compostable plastic packaging using intuitive logic. For instance, items that "look" compostable were put in food waste, items that "look" recyclable were put in recycling, and items that "look" like general waste were put in general waste. These automatic pathways may nonetheless be disrupted with the appropriate disposal instructions. While "do not recycle" may currently work to divert some types of compostable plastic packaging to general waste, it may not work for all, especially items with a common practice of being compostable, e.g., tea bags. Disposal instructions that explicitly mentioned food waste (e.g., "compost with food waste" vs. "compost") led to a statistically higher rate of disposal of compostable plastics in the food waste bin. Citizens valued the depiction of simple yet comprehensive, instructive, and explicit symbols in a logo for compostable waste, i.e., an arrow pointing into a bin, avoidance of associative symbols such as variations of the recycling chasing arrows symbol and depiction of a variety of different organic waste items that one can put in a food bin for local collection. Taken together, findings are in line with a substantial body of research showing that citizens have strong preferences for disposal instructions and logos that are clear, directional and explicit. Additional in-person studies and natural experiments in this area can improve the conclusiveness of findings.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

Ethics statement

The studies involving humans were approved by UCL Psychology and Language Sciences Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AA: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. AB: Writing – review & editing, Validation, Software, Investigation, Formal analysis, Data curation. DP: Writing – review & editing, Visualization, Validation, Supervision, Resources, Methodology, Funding acquisition, Data curation, Conceptualization. FL: Writing – review & editing, Supervision, Conceptualization. SM: Writing – review & editing, Supervision, Funding acquisition, Conceptualization. MM: Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition, Conceptualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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