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Influencing beach littering behaviors through infrastructure design: An in situ experimentation case study

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ABSTRACT

Marine litter is one of the most pressing problems of our time and a major threat to ocean health; much of it comes from land-based sources, including from beachgoer activities. This study investigates how product design could influence littering behaviors of beachgoers when applied to beach trash cans (TCs). Over the course of six weeks three differently designed TCs were placed on a Mediterranean Sea tourist beach in Israel while observers tracked the behavior of 536 nearby groups ("entities") of beachgoers. Researchers analyzed: a) entities' locational choices; b) materials discarded in the TCs; and c) littering behaviors around the TCs. Based on the data collected, a "motivating" TC design performed best, encouraging the highest level of beachgoer interaction. Further research is needed in more and varied beach contexts, but this type of initial interdisciplinary research suggests how the design discipline could contribute to preventing marine litter from land-based sources.

1. Introduction

Marine litter, mostly consisting of plastic in all shapes and sizes, is saturating our oceans, seas and rivers on a global scale (Serra-Gonçalves et al., 2019). It is a consequence of inadequate solid waste management practices, unsustainable product design and consumer choice, loss or discarding of fishing gear, cargo or ship-generated litter, irresponsible discharge of industrial waste, tourism and recreational activities, lack of infrastructure, and the public's poor understanding of the potential consequences of their actions (Jambeck et al., 2015). Experts warn that fossil-fuel derived plastic waste takes centuries to degrade; in a well-documented article on marine plastic pollution, Forrest et al. (2019) contend that over 5 billion tons of increasingly fragmented and dangerous plastics have therefore accumulated in our oceans, soil and air.

The majority of the plastic found in the ocean are tiny pieces of < 1 cm in size, which often started off as larger macro-litter with much coming from beaches (Bergmann et al., 2015; Cruz et al., 2020; Portman and Brennan, 2017; Slavin et al., 2012; Zielinski et al., 2019). There is no doubt that small and large plastics cause great harm to the marine ecosystem including to megafauna such as turtles, sea birds, and marine mammals which ingest and/or become entangled in the plastics with fatal or debilitating consequences (e.g., Fossi et al., 2018). Plastics are just one of the types of litter items found in seas the world over (Bergmann et al., 2015; Serra-Gonçalves et al., 2019).

In addition to being a serious risk to marine and coastal ecosystems, marine litter of all kinds has severe socioeconomic implications in coastal communities (i.e., on tourism, maritime transport, aquaculture, fishing industry and leisure) (Zielinski et al., 2019). It is therefore imperative to take actions now to keep litter from entering the marine environment. Developing means for preventing littering by beachgoers through the application of design methods to keep beaches clean is one of the many innovative ideas that should be explored as a way to address this problem (Cingolani et al., 2016; Portman et al., 2019).

As such, this paper highlights: a) the importance of experimentation with beach infrastructure design for influencing behavior related to beachgoer activity; and b) results from mixed-methods research that tests two designed prototypes against the beach trash can that is currently being used on the beaches in the case study area. It also includes lessons learned about experimental protocols from in situ testing of designs for behavioral change. The use of common and simple beach infrastructure in this type of testing is novel when applied to marine litter prevention strategies (Serra-Gonçalves et al., 2019) at least in academic work.

1.1. Pernicious effects of beach litter

The deleterious effects of littering behaviors on beaches can be assessed through the direct costs of keeping beaches clear of litter. Of course, not all beach litter is generated by beachgoers. Some litter arrives at beaches from the sea or it is land-based (as is beachgoer-

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generated litter), but it has been deposited on the beach by forces such as water or wind such that even if littering behaviors were completely curtailed, beaches would still not be completely clean (Galgani et al., 2015). In any case, in areas where coastlines make a significant contribution to the economy, the costs of marine litter are substantial (Newman et al., 2016) and therefore from a beach management perspective, definitely worth pursuing.

Mouat et al. (2010) calculated that the costs of litter removal average between €7000 and €7300 per km per year in the UK. In Belgium and The Netherlands, costs outlaid for cleaning beaches are even higher, coming to €34,000 per km per year. Other studies demonstrated the value people place on clean coastal environments (Cristiano et al., 2020). They have used such methods as travel costs or lost expenditures on hotels and lodging to assess the financial impacts caused by littering on beaches (Newman et al., 2016). Another way to evaluate the effects of litter is by the accumulated costs to various sectors of the economy. A study conducted in the Adriatic-Ionian region of the Mediterranean found that the total losses just to the fisheries sector from marine litter are estimated to be €18.19 million per year (Vlachogianni, 2017).

Besides considering the cost of keeping coasts clean and related economic impacts to various use sectors, there are numerous environmental impacts to litter on beaches, both direct and indirect (secondary). These include effects to marine life from megafauna to microorganisms from sessile to migrating life forms and effects due to the fact that litter serves as a vector for invasive species (Bergmann et al., 2015). There are also secondary effects to litter, such as the blockage of drainage conduits (Armitage and Rooseboom, 2000) which may be particularly egregious in coastal communities. All these effects have ultimately made marine litter one of the most pressing environmental problems of the current era with numerous entities, from private companies to NGOs to governments trying to reduce its quantities and counter its effects (Chen, 2015; Serra-Gonçalves et al., 2019).

1.2. A solution by product design?

As mentioned above, in a seminal paper on plastic litter in oceans published in *Science*, Jambeck et al. (2015) point out that a number of factors related to the coastal and adjacent-to-the-sea land environment have consequences for the dispersal of marine litter, e.g., inadequate solid waste management practices, unsustainable product design and lack of infrastructure. Product design in a broad sense could be applied to adapt beach infrastructure to address the problem, particularly when that infrastructure has to do with solid management practices. This begs the question whether beachgoers can contribute to solid waste management practices by increased use of properly designed waste collection infrastructure. A number of papers and studies have suggested this approach, both in relation to beach litter and to litter in other venues where it is the result of recreational activity (e.g., Hartley et al., 2018; Rangel-Buitrago et al., 2019).

De Kort et al. (2008) distinguished between explicit and implicit structural designs of infrastructure by focusing on the design of trash cans (TCs) in public spaces at train stations. The explicit TC design included a message on it which literally explained how to behave (i.e., prevent littering) in the setting with the premise being that this required the activation of social norms. Similarly, implicit activation, which included the use of mirrors on the TCs as part of the design in the same experiment, intended to influence personal norms as well. Overall, the study found that explicit norm activation is more effective than implicit activation. Researchers conducting the study found that an explicit norm works better in a clean environment, and also that its activation loses efficacy as time goes on. Further, the researchers found that implicit norm activation, considered more relevant to actual physical TC design, can work in an already littered environment and it becomes more effective over time (de Kort et al., 2008).

So far, it seems that experiments examining behaviors around litter prevention infrastructure, whether on beaches (e.g., Cingolani et al., 2016) or in other types of public space (e.g., de Kort et al., 2008), have generally investigated written or demonstrative designs using questionnaire survey methods rather than in situ observation. An outlying (exceptional) case are Bateson et al.'s (2015) observational experiments. For these experiments the researchers attached leaflets with anti-littering messages of different types to parked bicycles on a university campus, one of which included the image of watching eyes. The leaflets with the watching eyes, when detached by passersby, were substantially less likely to be littered than control leaflets without the eyes. Furthermore, littering lessened when there were other people in the immediate vicinity or when the subject was alone (Bateson et al., 2015).

As an important step in the direction of keeping litter off beaches and out of the marine environment while at the same time building on past studies, design literature and experimentation, we explore the idea that marine litter can be addressed, even if not completely prevented, by the improved design of beach infrastructure. We focus on beach TCs as one element of this infrastructure. Our premise is that principles of persuasive design can be used to prevent some portion of marine litter. Persuasive design, often used to change behaviors (see Li-hsing, 2016; Portman et al., 2019), is enlisted to increase the use of the TCs and thus prevent littering behaviors that spoil beaches.

Litter-spoiled beaches have been pointed out as a particularly acute problem in the Mediterranean Sea (Constant et al., 2019; Gündoğdu and Çevik, 2019; Hartley et al., 2018; Mansui et al., 2020). There are a number of reasons for this, one being that the Mediterranean is an enclosed sea with a slow flush and exchange rate, two phenomenon that exacerbate all types of pollution (Amengual and Alvarez-Berastegui, 2018). Further, environmental awareness among the Mediterranean's surrounding populations is low, leading to much unregulated activity with high density along its coasts and overexploited beaches (Laubier, 2005). As such, increasing beach recreationists' participation in keeping beaches clean through better design of TCs could have a noticeable impact on helping to make beaches in this area of the world cleaner.

1.3. The Israeli case study

As mentioned, the Mediterranean Sea has been described as one of the most affected marine environments with regards to marine litter (Baini et al., 2018; Fossi et al., 2018). A recent study showed that the total annual input of plastic to the Mediterranean is about 100,000 tons from which 50% likely originates from land-based sources, 30% from riverine systems and 20% from maritime navigation (Liubartseva et al., 2018).

From among the Mediterranean Sea's coastal nations, Israel's sandy, straight beaches serve as a type of litter “conduit” exhibiting high mobility and low persistence of litter with relatively good self-cleaning capacity (Bowman et al., 1998). However, the country has a rapidly growing population, a high-standard of living and not particularly high environmental awareness (compared to other OECD countries) with the litter problem only expected to get worse (Brennan and Portman, 2017). This renders Israel's beaches generally crowded and with significant amounts of litter (Pasternak et al., 2017; Portman and Brennan, 2017; Portman et al., 2019), especially during the summer months.

The experiment reported on here took place on Sironit beach in the city of Netanya, a popular spot for summer local beachgoers as well as for many tourists (see Fig. 1). The beach is one of the countries' busiest Mediterranean beaches; it is among another 13 city (urban) beaches along the coast that have been designated officially as bathing beaches (i.e., with seasonal lifeguard and other municipal services, such as trash pick-up, infrastructure maintenance, etc.).

A 60 m long and 20 m wide stretch of this beach was chosen as the survey area because it is relatively open (without lounge chairs and other obstructions). This allowed two trash cans to be placed 30 meters (m) apart and area enough for two scouts (hereafter “observers”) to record and track the behaviors of the beachgoers before them (see

Fig. 1. The location of the in situ experiment: Sironit Beach, Netanya Israel. On the right is a locus map showing the larger cities of Israel with Netanya pointed out by an arrow.

Materials and methods).

The records compiled from the in situ experiment allowed some conclusions to be drawn about the effectiveness of the trash cans in keeping litter off beaches and therefore preventing it from getting into the marine environment. A comparison between the design of two newly developed TC prototypes to a third existing and commonly used beach TC lead to insights about the influence of design in preventing beachgoer littering behaviors. These insights were based on qualitative descriptions of behavioral interactions and the collection of spatial and other quantitative data, all related to interactions of beachgoers with the TCs.

2. Materials and methods

The experimental study investigated beachgoers behavior in relation to three structurally different TCs placed on the beach in Netanya, Israel. It used persuasive product design principles to construct two TC prototypes. These TCs were then tested in the field against the effectiveness (or lack thereof) of the existing, commonly used TC (see Fig. 2), i.e., the third "control" design. The ultimate objective of the experiment was to identify elements of a "designed" TC that will encourage the greatest amount of use. The in situ experiment served as an observational study that draws inferences from a sample to a population.

There were two main parts to the study: a) observation of behaviors of the beach visitors in relation to the three different TC types; and b) identification of amounts and types of litter collected during the experiment in each of the TCs. The former part of the study which observed behaviors had two sub-parts: any interactions with the different TCs were observed and recorded while observations were made simultaneously of where visitors located themselves for their stay on the beach in relation to the different TCs.

2.1. TC design

Work done over the course of a year prior to the actual experiment lead to the design of the two-prototype beach TCs and to final protocol development for the experiment. Creation of the two prototypes TCs was influenced by product design literature, particularly by literature on persuasive design (Li-hsing, 2016; Oinas-Kukkonen and Harjumaa, 2009) and on design for sustainable behavior (Lilley et al., 2018). Further influencing the design of the TC prototypes were insights from the research staff, an on-line survey of beachgoers about the littering-related behaviors, beach managers interviews and a questionnaire administered to Blue Flag beach (see Lucrezi et al., 2015) program managers.

A half-day participatory design ideation- workshop was held by the research team in December 2017 (with the help of EcoOcean) that also influenced the TC design (detailed in Portman et al., 2019). Various agents concerned with the subject of marine and beach litter, beach managers, researchers and NGO representatives participated in the workshop. Participants brainstormed on the following subjects: materiality, exhibited values, properties, form, visuals, placement, text for the public, siting, interaction with the beach goers, education and publicity.

The prototypes and the experimental design were also informed by a pilot conducted some months before in which two makeshift prototypes were used (see Portman et al., 2019). These TCs used a simple printed half meter squared sticker pasted on a cardboard stencil wrapped around the existing control TC. The large stickers showed an implicit and explicit message, similar to (and based on) designs used in previous experiments involving TCs (i.e., de Kort et al., 2008).

To develop the two prototype TCs used for the full in situ experiment, the research team worked closely with a professional industrial designer over a period of 3–4 months leading up to the summer of 2018, when the experiment was conducted in the field. The designer was instructed to ensure that differentiation between the designs would help single out TC design elements that were most influential in preventing littering of beaches. All aspects of the design incorporated factors raised in the earlier research (Portman et al., 2019), i.e., from idea to form, consideration of materials resistant to weather conditions, resistance to vandalism, animal (principally cats and birds) scavenging and maintenance issues.

For the full in situ experiment, one prototype was categorized as an "enabling" design and the other as "motivating" (see Fig. 2). The enabling (TC_A) design was a simpler, more straight-forward design that aimed to draw attention using color (denoting water and beach environs) and theme (denoting a jellyfish and water). The second motivating (TC_B) design was an interactive trash can. In addition to drawing attention with color and theme, the TC invited users to interact with it. Users could insert bottle caps or smashed plastic cups into the TCs top ring cap. The inserted caps or plastic cups would then slide down a shoot that winds around the TC's main basket, making a rubbing noise thus drawing both audio and visual attention.

Four prototypes were built by the designer, two of each design. Only two were placed in the field at a time so that one backup TC of each prototype was available. This turned out to be important because minor maintenance was needed from time to time over the 18-day experimental period.

Fig. 2. The two prototypes TCs (TC_A and TC_B) and the control TC_C. The top row photos show the schematic design of the first two prototypes with bottom row pictures showing them in situ.

2.2. *In situ experimentation*

The TCs (A-C) were randomly set out on the beach during the same hours every day three consecutive days per week for two three-week sessions, one session early in the summer bathing season and the second towards the end of the bathing season (See Table 1). Mondays, Tuesdays and Wednesdays were chosen as consistent observation days, in order to avoid bias between the different weeks; the afternoon hours that were chosen for the experiment are considered particularly active times on the beach. Two TCs out of the three (TC_A, TC_B or TC_C) at a time were placed for the daily observation at approximately 30 m from each other according to the schedule. This rendered a total of 54 h of observations, all taking place consistently (at the same days of the week and at the same scheduled daily times) over the summer vacation period.

Table 1
The columns indicate the order and location of the TCs during the first and second rounds of three consecutive weeks each. North and south indicate the two possible TC positions shown in Fig. 4.

	Day	Week 1		Week 2		Week 3	
		South	North	South	North	South	North
Round I June 25–July 11, 2018	Mon	B	A	A	C	B	C
	Tues	B	C	C	B	C	A
	Wed	B	A	C	A	C	B
Round II Aug 13–29, 2018	Mon	C	A	A	C	B	C
	Tues	B	C	C	B	C	A
	Wed	B	A	B	A	C	B

The handling of the TCs and their content was carried out by beach workers only, in order to avoid drawing attention to the observers. The two observers sat “undercover” within the study area for 3 h each day, from 14:30 to 17:30 in the afternoon and recorded information about beachgoer “entities”. An “entity” consisted of a group of persons that arrived and settled together in the study area (hereafter “entity”). One of the two observers recorded locational information and details such as the number of individuals in each entity and demographic details such individuals' approximate age and gender. The second observer focused on identifying behaviors directly related to littering, as explained below.

The experiment provided information in three ways. Firstly, observers conducted spatial tracking. While not exposing their intent or drawing attention to their whereabouts or activities, the observers recorded where each entity sat in the study space on a schematic hardcopy sheet. The locations were recorded in relation to a) the TCs; and b) each other; c) the water line and limits of the study area. While this resulted in only general locational indication and analysis, it was accurate enough to inform about the entities' willingness to be in proximity to TCs, or conversely, to indicate TC avoidance.

The second activity of the observers provided insights about the type of waste discarded by beachgoers into the TCs. For this part, the contents of each TC were sorted, weighed and categorized at the end of each 3-hour observation period. The categories used for sorting the deposited waste were adapted from the MSFD Master List which consists of 165 categories of beach litter (Joint Research Centre of the European Commission, 2013).

To simplify, we grouped categories of discards in the TCs such that waste ended up being of 7 types, sorted by material or by the activity associated with its generation. Categories were: drinks, food-stuff, recreation, toys, smoking, hygiene-sanitary and miscellaneous. The grouping was done to simplify identification and description of the material as recorded in the Behavior Tracking Form described below. The contents were counted by the number of items found in the bags belonging to each category. Items were counted, summed for the week by TC and then "normalized" by dividing item totals by the number of times each TC was in the field per week. For example, the divisors for the first week were for TC_A: 2, for TC_B: 3 and for TC_C: 1 (as taken from Table 1). Sums for all weeks by TC_x are reported in the Results section for the three most common item categories.

The third type of information recorded by the observers documented entity behaviors, such as the burying of cigarette butts and engagement in litter producing activities such as picnicking. Two forms were used for recording these observations which allowed cross-referencing of most of the tracked behavioral information. The first is an entity's registry form (hereafter Log Form (see Appendix 1)) on which the observers recorded a basic description of each entity, an assigned reference number, the time during which the entity was observed on the beach and general descriptive characteristics such as the number of members in the entity, estimations regarding the members' approximate age, nationality and relationship (e.g., friends, father and son, grandparent, etc.). The second was a more detailed form (See Appendix 2: Observer Protocol and Behavior Tracking Form) in which the observers recorded behaviors of each referenced entity.

The outcome of the first recording activity described above was analyzed using QGIS, version 3.4. The three most important variables analyzed with regard to the entities' location were: numbers of beachgoers in each coded entity, distances from the TC and the time spent there. Since observation sessions were time-limited to 3 h daily, a group that arrived later during this period would have a shorter recorded time than one arriving earlier. Therefore, we used only the size of the entity (i.e., the number of members in each entity) and the inverse distance (one divided by the distance in meters to the closest TC) as weighting factors. This calculation, termed the Weighted Contact Score (WCS), assumes that a larger number of people willing to sit in close proximity to a particular TC indicates some level of interaction with it. Interaction with a product, in this case the TC, is assumed to lead to its use (Niedderer et al., 2017).

To calculate the WCS, the number of times a TC was in the field (the number of opportunities), was used for normalizing: for TC_A ten, for TC_B twelve and for TC_C fourteen (See Table 1 above). Therefore,

$$\text{Weighted Contact Score } TC_x = \frac{\sum_i^n 1/_{D_i} * P_i}{TC_D} \text{ where } i \text{ is the observation} \quad (1)$$

Further, P is the number of persons in each entity; D_i distance of that entity to the closest TC and TC_D is the number of days TC_x was situated in the field.

The categories of information recorded on the Behavior Tracking Form (See Appendix 2) included spatial information and additional general descriptive characteristics of each entity. Spatial information collected noted the approximate distance from the nearest TC and approximate distance from other groups (for both, 0–3, 4–10, 11–15, and > 15 m). This information was cross-referenced with information in the Log Form. It would have been overburdening for the two observers to track all the entities in the study area, which was on average ~30 entities for a three-hour period each day. Therefore, they had specific instructions to track only those entities that they could see well enough to follow and record consistently and without obstruction, averaging ~14 entities per day.

Behaviors were categorized as a) those during the beach stay, b) those at the end of the stay, c) general behaviors, and d) behaviors related to smoking. There was also a miscellaneous category. Behaviors during the stay included, for example, "rising to dispose of waste in TC" and "burying litter in sand". Those at the end of the stay included "cleaning the area before departing" and "leaving litter outside of or next to the TC" (See Appendix 2).

The questions we sought to answer by recording and analyzing behaviors related to the use of the TCs included: Did the entity throw their litter into the TC? Did an entity get up to use a TC during their stay or did they use the TC only upon leaving the beach? What type of interactions occurred with the specific TCs? The recording of this data in sections that correspond to these questions gave us qualitative information on the quantity and types of interactions that took place between entity members and the three different styles of TCs. Among more general questions answered by the behavior tracking part of the study were: Did the entity take their litter with them when leaving the beach? Did the entity actively clean the area around where they were located at any time during the visit?

3. Results

As explained, inferences were drawn about each of the TC's design by comparing the performance to the two prototypes to that of a third "control" design. Performance consisted of behavioral decisions made by the entities (e.g., locational relations and interactions) and litter items in each TC as tallied at the end of the 3-hour daily observation period.

Over the course of the 18 days, 536 entities were observed. These entities experienced the beach usually by sitting, at a median distance of 16 m (population $\sigma = 8.36$), nearby the TCs. The median number of persons in each entity was 2 (population $\sigma = 1.567$). A total of 1235 persons were observed on the beach during the entire 6 weeks of experimental period. Two hundred and fifty-one entities from among all the entities observed (~47%) had their behavior specifically described and recorded during their beach visit using the Behavior Tracking Form.

3.1. Results: TC content analysis

A list of 34 different materials were anticipated to be found in the TCs and therefore appear in the form designed to record the materials that beachgoers discarded in the TCs (See Appendix 3: TC Content Analysis Form). In the end only a few of these 34 "line item" materials were commonly found. The line items were grouped together and tallied by general categories from among the seven (see Materials and methods section).

The most commonly discarded items were: drink containers, food related items and plastic bags. The results of the TC content analysis for these items were normalized by the number of times each TC was placed in the field. The comparison shows that the greatest numbers of these items were found in TC_B (see Fig. 3). Also, these items were more often discarded in TC_A then in TC_C. This is a significant finding and seems to suggest that TC_B, the "motivating" model that encouraged interaction, was the most successful at promoting the collection of these three most commonly discarded items from among potential beach litter.

3.2. Results: location of entities vis a vis the TCs

From an analysis of where entities located themselves in relation to the TCs as tracked by the observers, again we see that there is more willingness for a larger number of people to sit closer to the newly designed prototypes than to the control TC_C. Fig. 4 gives an example of how the calculations of size of entity and distance from TCs were tracked showing how the entities were dispersed around TC_A and TC_B during the first day of observations. The resulting comparison of Weighted Contact Scores (WCS TC_x calculated via Eq. (1)) is shown in Fig. 5.

The fact that TC_B with a WCS of 3.85 indicates that larger entities (i.e., with greater number of members) located themselves closer to that

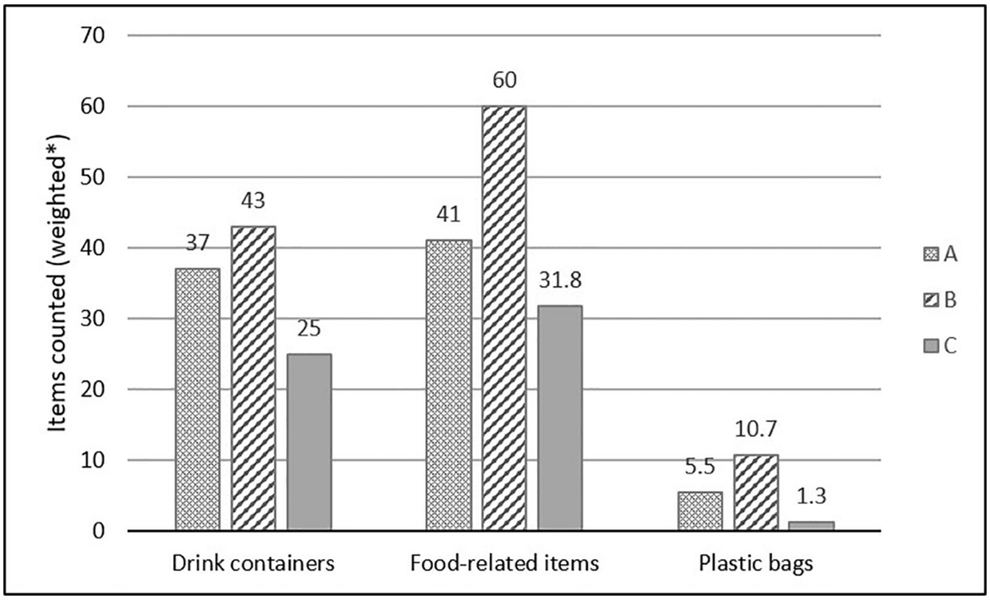

Fig. 3. Results of content analysis for the 3 most commonly discarded items found in each TC. The chart shows a normalized (weighted) tally of items, proportional to the number of times that the TC was located in the field (see Materials and methods).

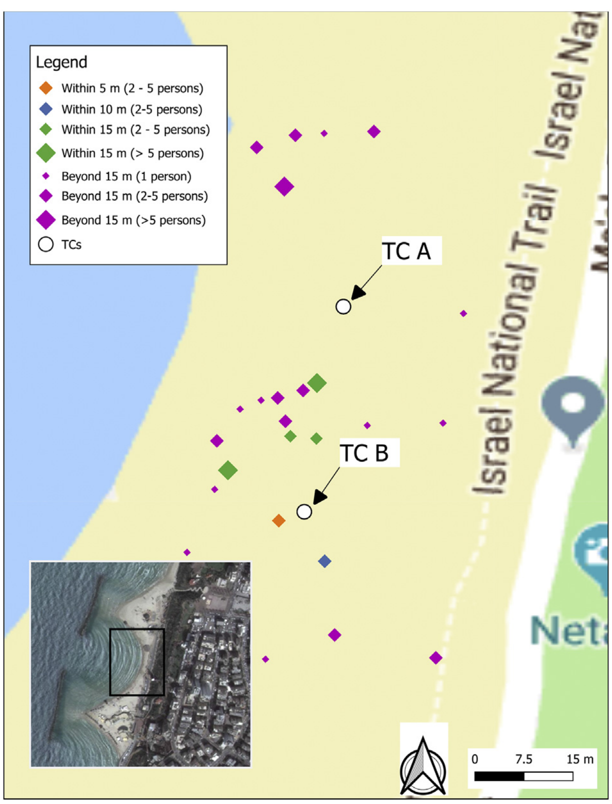

Fig. 4. GIS analysis of how beach-user "entities" located themselves in the study area as recorded for Day One (25.6.2018). Diamonds indicate entities according to size (number of persons) and where they sat in relations to the TCs. The rectangle in the inset map shows the general study area location of the larger (background) map.

prototype. The second highest WCS of 3.07 was associated with TC_A indicating that beach visitors were more willing to sit next to this prototype than to TC_C, with the latter being the least attractive to visitors with a WCS of 2.95.

3.3. Results: qualitative behavioral observations

The behavior-tracking form used by the under-cover observers, while designed to provide qualitative information, could have easily resulted in quantitative data as well. This is because observers recorded the number of times a behavior was observed for each entity. However, as noted in the Materials and methods section, not all the 536 entities observed were tracked for their behavior.

Under each of the main behavioral categories listed on the form, several behaviors were recorded as being notably more or less common. The first and second most common behaviors recorded were respectively, "Rising to throw waste into the closest TC" (ranging from 5 to 20 times recorded per day) and "put out and left cigarette butts in sand" (from 2 to 12 times per day). In general, considering that not all beachgoers smoke, there was quite a bit of activity related to cigarette butt disposal. Many instances of either use of the ash trays of the two prototype TCs (TC_A and TC_B) or the disposing of cigarettes and cigarette butts in the TCs was recorded, although not more often than cigarette butts being disposed of on the sand, either being buried or just thrown down.

The most interesting and significant information was that of unusual and specific interactions with the TCs, as recorded on the Behavior Tracking Form in free text, i.e., not as one of the ascribed behaviors that could be marked and counted. The most interesting of these was that the same visitor (a woman) chose to closely interact with TC_B on two separate days. During the first day, she closely observed the TC and looked at the drawings on its base and then came back to photograph it. The next day, she again photographed the same TC_B. Another unusual behavior was the use of TC_B as a basket for a game of beach basketball. This indicated the incidence of interest and interaction with that prototype design in particular.

General problematic behaviors that arose were those of plastic bags (6 recorded occurrences) and paper flying away (one recorded). Overall, beachgoers did not make attempts to catch them or run after them. Similarly, there were a few days (12 out of 18 days) that at least one entity left litter on the beach when departing. On the encouraging side, on a third of the days (6 out of 18) entities were observed actively cleaning the beach around where they sat. It was also interesting that beachgoers made special trips to the TCs more often than they disposed of waste on their way out. This suggests that getting up to dispose of

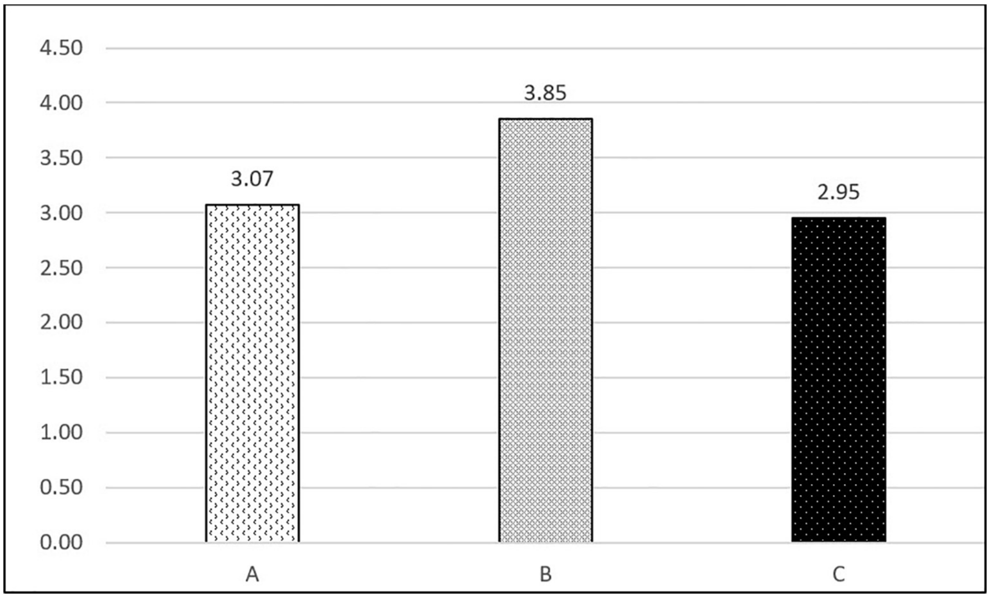

Fig. 5. Calculated Weighted Contact Scores (see Materials and methods) show an advantage to the designed prototype TC_A and TC_B over TC_C based on observations of 536 entities.

waste while spending time on the beach is an activity in and of itself. Also, it suggests that beachgoers prefer not to have their litter and disposable waste close to them over time, even though several instances whereas visitors took their litter with them upon leaving the beach were observed and recorded.

One of the important lessons learned from use of the forms for recording of behaviors by the two observers was that more thought needs to go into form design. Some of the behaviors listed ahead of time were too similar, and in some cases, had little to do with the TCs and their design. The most salient example of this is the two behaviors "put out cigarette and left in sand" and "disposed of cigarette butt by throwing them on beach". For the purposes of this study which focused on the design of TCs, the distinction between the two behaviors is unnecessary.

Finally, it seems that as the period of the experiment progressed it seemed that more specific actions and behaviors were recorded on the forms. This perhaps indicates that the observers were more attentive, or that they gained experience identifying certain repeat behaviors, categorizing and recording them. The three behaviors which did not vary over time were: a) "rising to throw waste into the closest TC", b) "put out and left cigarette butts in sand", and c) "disposed of cigarette butts by throwing them on the beach". All three of these remained consistent throughout the six-week experimental period, with the first two (a and b) being, as mentioned, the most common.

3.4. Study limitations

This type of highly interdisciplinary work is novel and innovative. At the same time, bringing the design field to bear on the planning of beach management infrastructure is both important and challenging. Of note is the learning process and the impression that while replication is possible, it would have to include a number of facilitating adjustments that would lead to greater accuracy, lower experimental costs and improved efficiency. Special challenges were discerned over time and could only have been addressed if the experimentation went on for a longer period of time or perhaps another full summer season.

Firstly, the spatial orientation of the entities with relation to each other and to the TCs could be tracked more exactly if a GPS is used. This could be done by having observers approximate themselves to the tracked entity to record a position. However, as mentioned in the Materials and methods section, the risk is of being too obvious and jeopardizing the anonymity of the observers.

Another issue was that of time. Ideally time spent in the proximity of a TC would show willingness to use it and have it on the beach. Our experiment was limited in that entities were recorded only from 2:30 in the afternoon and until 5:30 whereas they may have continued to sit on the beach for far longer or they may have come much earlier. Observing should take place whenever the regular beach infrastructure is present, or for the maximal period of time beachgoers sit on the beach, ideally for the entire day, or at least during lifeguard hours when the greatest amount of beachgoers would be active in the study area. While there were on average ~30 entities observed per day, this is still a small number. A greater number of experiment days and hours would render enough perhaps for a statistical analysis without using the weighting system described above.

The analyses, both the spatial GIS analysis and the TC content analysis, were complicated by the rotations of the TCs every day during the week. The idea was to minimize biases that might have been due to interactions between the TCs on each other. This could have also been avoided by having two TCs of the same type rotated by day of the week (provided that the total number of days is a multiple of three). However, this might have resulted in bias between the days.

The need for normalization of the results by considering the number of times each TC was set up in the field could be avoided by having one of each of the TC type placed in the study area simultaneously during every observation period – rendering a total of three TCs place in the field each day; however, this would likely require a larger study area being chosen with a more even spatial layout, rather than in a bay configuration. If this were the design, a larger area should be used so that influences of one TC on another would not occur.

Despite the challenges of the experimental design and operation, the results clearly show that TC_B was more frequently interacted with, collected more waste and encouraged beachgoers to sit close by. Obviously, these findings are comparative in nature and not absolute. Yet, the fact that all three of the parameters followed and tracked, recorded and analyzed, indicate a particular prototype and thus likely greater efficiency from a functional perspective, coincides what many product designers (e.g., Li-hsing, 2016; Lilley, 2009; Lilley et al., 2018) have claimed for some time: design can influence sustainable behavior. Now designers need to meet more often with scholars of behavioral psychologists seeking to change environmental behaviors addressing litter (e.g., Bateson et al., 2015; Cingolani et al., 2016; de Kort et al., 2008).

4. Conclusions

The interesting results of the experiment conducted using the designed TC prototypes, particularly the motivating TC_B design, suggests that persuasive product designs can have an impact on beachgoer behavior. This confirms the importance of interdisciplinary and transdisciplinary work that brings a number of fields to bear on a major environmental problem, one that has been a focus of concern for marine ecosystem health, protection and conservation for some time (UNEP, 2009).

Product designers concerned about sustainable behaviors have been promoting the idea that their profession can make significant impacts for improved environmental quality and protection in many areas (Ben Rejeb and Roussel, 2018; Bhamra and Lilley, 2015; Clune and Lockton, 2018; Gardiner and Niedderer, 2017; Lilley et al., 2018). Our study has made a more focused contribution by bringing some design principles to bear on the prevention of beach litter in a planned and controlled setting. Further work needs to be done to both address the listed limitations of this study, as well as to collect more data by increasing observations under different conditions and contexts.

With regard to the questions answered by the study, it seems that a TC that is both eye-catching and allows for playful interaction could be more successful than mundane, smaller and less colorful TCs. But again, as stressed in previous papers addressing this question (i.e., Portman and Brennan, 2017; Portman et al., 2019) any emphasis on addressing beachgoers participation in keeping beaches clean, whether through use of TC or beach cleaning activities (e.g., Zielinski et al., 2019), should be part of a wider, broader program. Such a program must apply myriad methods, incentives, policies and clean-up practices to address the significant and nefarious problem that marine litter from land-based sources has become.

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Credit authorship contribution statement

Michelle E. Portman: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Supervision, Visualization, Writing - original draft, Writing - review & editing, Project administration, Validation. **David Behar:** Project administration, Supervision.

Declaration of competing interest

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

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