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Evidence of 'Green' behaviours: Exploring behavioural traces of pro- and anti-environmental behaviors☆

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ABSTRACT

The current climate crisis requires pro-environmental behaviours (PEBs) to be developed, engaged in, and spread to other people. Behavioural traces, i.e. evidence of other people's pro-environmental behaviour left in the shared environment, have shown to influence people towards being more pro-environmental. However, systematic research into behavioural traces of PEBs is missing. In a set of three surveys, we investigate which behavioural traces correspond to a number of pro- and anti-environmental behaviours identified from previous literature, how frequently these behavioural traces are encountered, their relation with engagement in behaviours, and whether behaviours can be inferred from traces. All studies are survey-based with a mix of open-ended questions (Surveys 1 & 3) and rating scales (Survey 2). We use network analysis to identify partial correlations between behaviours and traces. A total of 66 traces uniquely attributed to 36 pro- and anti-environmental behaviours were identified. On average, each trace is observed monthly. Noticing traces correlated with engaging in related behaviours in 24 instances. Participants report that if they saw a trace more frequently, they expect they would be more likely to adopt the behaviour that produced the trace. Finally, participants were generally able to infer the causing behaviours when only presented the traces. We show that unique behavioural traces exist for a number of pro- and anti-environmental behaviours. Traces are noticed and relate to the constituting behaviours based on correlational and self-report evidence. Because of the wide variation between behaviours and their traces, further research into specific behaviours is warranted. Use of these findings for interventions are discussed.

The current climate crisis requires urgent action to reduce global greenhouse gas emissions and increase protection of the environment (Masson-Delmotte et al., 2018). Along with policy changes, this effort includes increasing individual pro-environmental behaviours. Understanding what makes someone act pro-environmentally is key to this challenge. A pro-environmental behaviour (PEB)[1] is a purposefully chosen action to use fewer resources or emit less greenhouse gases compared to the default (more prevalent or convenient) behaviour (Stern, 2000). A PEB could not just harm less, but benefit the environment (Steg & Vlek, 2009), for instance when planting trees. What constitutes a behaviour as pro-environmental, however, is usually defined by the context and better expressed as degree rather than in absolute terms. If the choice is between public transport and cycling, cycling is more pro-environmental; yet public transport is more pro-environmental compared to driving. Driving, in turn, has less impact than flying (measured in kWh/person-kilometre; MacKay, 2008).

Engaging in a PEB generally bears some cost to the individual, and future benefits are uncertain and depend on the overall engagement in similar behaviours by the group. This resembles the well-known social dilemma of the *Tragedy of the Commons* (Hardin, 1968), for which it has been found that people are more likely to cooperate if they see other people also cooperating. But how do people know that others are engaged in PEBs? One potential route is via behavioural traces. A behavioural trace is the evidence of a behaviour left in the shared environment and distinct from direct observation of that behaviour (Topf & Speekenbrink, 2021). Examples of behavioural traces are a bike left outside a building that someone used to cycle there, or the recycling box left set out on collection day as a trace of the separation behaviour of

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[1] We use the term 'pro-environmental behaviour'; other terms in the literature include 'responsible environmental behaviour' (Hines et al., 1987), 'environmentally significant behaviour' (Stern, 2000), 'ecological behaviour' (Kaiser, 1998) or 'green behaviour' (The British Psychological Society, 2011), amongst others.

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different materials. The concept of behavioural traces is borrowed from research on social insects, where environment-mediated coordination can explain the paradox that non-communicating insects can cooperate effortlessly (Theraulaz & Bonabeau, 1999). Coordination via behavioural traces is ubiquitous in people's everyday lives (Parunak, 2005). We follow paths that have been trodden by others, either hoping it will lead somewhere interesting or simply using it because it is easier (Helbing et al., 1997), we buy items because others have done so as well, manifested as empty shelf space (Gierl & Huettl, 2010; Roy & Sharma, 2015; Verhallen & Robben, 1994; Worchel et al., 1975), and we are more likely to leave an item unwashed in the sink if others left theirs as well (Raihani & Hart, 2010). There are thus good reasons why behavioural traces could be instrumental for adopting behaviours in humans, as well, and particularly PEBs. A meta-analysis of 84 field-experiments showed an effect of Cohen's $d = 0.59$, 95% CI [0.52, 0.67], for behavioural traces on behaviour (here: "implicit descriptive norms"; Bergquist et al., 2019). People are less likely to litter in a clean (vs littered) environment (Cialdini et al., 1990; Keizer et al., 2013), are more likely to turn off lights and computers when they initially found the room with those switched off (Bator et al., 2014; Bergquist & Nilsson, 2016; Dwyer et al., 2015; Oceja & Berenguer, 2009), donate when others have already donated (Jacob et al., 2018; Kubo et al., 2018; Martin & Randal, 2008; Reingen, 1982), and install solar panels where others have installed them nearby or recently (Baranzini et al., 2017; Bollinger & Gillingham, 2012; Carattini et al., 2019). Importantly, behavioural traces are distinct from other forms of communication.

First, and in contrast to direct communication and observation, behavioural traces do not rely on social signals, such as similarity. People tend to trust information from people more if they resemble them (DeBruine, 2002) or belong to the same group (Brewer, 2008), and even avoid useful information from an out-group source (McDonald & Lohse, n.d.). Since the observation of a behavioural trace is generally divorced from social appearance, one can learn from a wider range of people, meaning that behaviours are more likely to spread throughout the whole population, rather than only in a small section of highly similar people ('bubbles' or 'echo-chambers').

Second, behavioural traces can also be more trustworthy than direct communication, especially when created as the mere by-product of a PEB. Unlike 'cheap talk' (Farrell & Rabin, 1996), where someone could promise to engage in a behaviour but never does so, the traces could not have been created without actually engaging in the behaviour (Dipple et al., 2014; Marsh & Onof, 2008). This is especially crucial to consider in the case of PEBs, where free-riders who convince others to be more pro-environmental without doing so themselves, still enjoy the benefits such as clean water and fresh air. Because it is crucial that as many people as possible engage in PEBs for it to make a noticeable difference, trustworthy signals of engagement are more likely to convince others to also join in.

Third, agent and observer do not have to be present at the same time for the observer to be able to make an inference about the behaviour. This means that behavioural traces are available for a much longer period than their constituting behaviour, so that even very fleeting behaviours can have an effect long after they took place. Traces can also be witnessed by many more observers, and thus have the potential to influence more people than either direct observation or direct communication could. For instance, the relatively private separation behaviour is made visible to others through the curbside recycling box; while observing someone arrive by bike depends on being present at the right place and at the right time, the bike will be visible for many hours.

It is important to note that behavioural traces have been referred to under different names. For instance, Jacob et al. (2018) looked into the effect of supposedly already donated coins in a jar (as well as clothes in a bag) on donation behaviour (effectively behavioural traces of previous donation behaviour) and refer to this as a type social proof (the concept of social proof captures people's tendency to use information about how others have behaved in order to determine the appropriate behaviour in a given situation, see Cialdini & Trost, 1998). *Behavioural residue*, meaning 'the physical traces of activities conducted in the environment' (p. 381; Gosling et al., 2002), or *cue* (Gosling et al., 2005), as well as *behavioural product* (Lange & Dewitte, 2019) have also been used to describe what we would call behavioural traces. For instance, Gosling et al. (2005) had participants make judgements about someone's personality based on the state of their personal living spaces. This included objects such as books, magazines and clothes (and whether they are organised/disorganised, homogenous/varied, many/few), and other physical evidence such as smells and noises, but also more subjective features such as whether the interior is 'Cheerful (vs. gloomy)' and 'Stylish (vs. unstylish)' (p. 695). These observations were all summarised under the term 'cues', although we would only call the physical evidence such as objects, smells and noises 'behavioural traces'. Since 'cue' can refer to qualitatively very different types of information, ranging from the clothes someone wears to nonverbal behaviour such as smiling or frowning (Kenny et al., 1992), rather than using terms such as 'cue' or 'social proof', we thus use *behavioural traces* when referring to 'physical evidence of behaviour'. Similarly, the areas of social learning, public information use and social eavesdropping also often include variations of behavioural traces under different names and without strict delineation from other sources of information, such as direct observation (Bonnie & Earley, 2007). Another important term is *implicit descriptive norms*, defined as norms that "communicate the social norms by subtle cues in the environment, indicating what other people have done or (dis)approve of" (Bergquist et al., 2019, p. 2). Descriptive social norms, however, generally make reference to what proportion of other people engage in that behaviour, whereas a few people could have caused the behavioural traces (e.g., one person could have switched off all the computers in a room), denoting no norm at all but the preference of a small, dedicated group. Behavioural traces thus *can* be a reflection of social norms, but do not necessarily have to be. We decided to use the term 'behavioural traces' to refer to physical evidence, independent of whether they stem for a majority or individual's behaviour, and because this includes both 'cues' (inadvertently sent information) as well as 'signals' (intentionally sent information) and cannot be confused with other terms that include other forms of information, such as nonverbal communication and direct observation.

When assessing the impact of behavioural traces, studies so far have only looked at a small set of specific behaviours and not at PEBs in general. The main purpose of the current study is to assess the effect of behavioural traces on a wide variety of PEBs. We aim to answer the following questions: (a) What are common behavioural traces of PEBs?; (b) Do people notice these, and if so, are they interpreted as evidence for the constituting behaviours?; (c) What is the relation between observing behavioural traces and engaging in PEBs?; and (d) Is the frequency of observing one behavioural trace correlated with the frequency of observing another trace, which would indicate individual differences in the likelihood of perceiving any traces? To do this, we first identify PEBs from the previous literature, followed by obtaining behavioural traces for these (Survey 1). Next, we investigate how frequently these traces are encountered and whether there is any relation between the observation of traces and engaging in pro-environmental behaviours (Survey 2). Finally, we test that the traces generated in Survey 1 are recognised as evidence for the initial pro- and anti-environmental behaviours (Survey 3).

1. Survey 1 - Generating behavioural traces

Survey 1 was conducted to identify possible behavioural traces for common PEBs previously mentioned in the literature, as well as corresponding anti-environmental behaviours.

1.1. Methods

1.1.1. Identification of pro-environmental behaviours

To identify PEBs, we conducted an extensive literature search.[2] We searched for studies that (a) were from the UK (because behaviours and their traces may differ by country), (b) used quantitative measures, (c) looked at more than one behaviour, (d) had a representative sample, (e) had at least 500 participants, and (f) were conducted within the last 10 years (2009–2019). The latter restriction was included under the assumption that prevalence and perceptions of PEBs may have changed rapidly over previous decades (Ballew et al., 2019). This search delivered 311 results. After sighting abstracts for the above criteria, 30 studies remained included. Of these, a further 25 were excluded because they did not report or measure individual PEBs, were based on existing data, or used unrepresentative samples. The remaining five studies (1 UK, 3 England, 1 Ireland & Northern Ireland) asked participants to rate how often they engaged in a number of PEBs (see Table ??; Whitmarsh, 2009; Huebner et al., 2016; Lavelle et al., 2015; Whitmarsh et al., 2017; Whitmarsh & O'Neill, 2010). Additionally, we included items from three waves of the Energy and Climate Change Public Attitude Tracker, compiled by the UK Department for Business, Energy and Industrial Strategy (BEIS, 2017), and the UK Survey of Public Attitudes and Behaviours toward the Environment (SABE; DEFRA, 2009). In summary, we identified 62 PEBs from previous literature. We added the corresponding anti-environmental behaviours to this list before presenting the behaviours to participants in Survey 2.

1.1.2. Participants

Thirty-nine participants were recruited as volunteers via word-of-mouth and social media ($N = 21$) as well as from the University College London (UCL) psychology subject pool ($N = 18$).[3] The latter set of participants were students who received course credit for their participation. The survey had approval from the UCL Research Ethics Committee.

1.1.3. Procedure

In the instructions, the concept of behavioural traces was explained as follows: "A behavioural trace is any physical evidence or artefact of that behaviour, but not the behaviour itself. Note that traces are generally objects but also include noises, smells and digital evidence (e.g., websites)." This definition was followed by examples ("a bike chained to a rail outside your home or workplace"; see Supplementary Materials for complete instructions). Next, we asked participants two questions to ensure that they understood the difference between *direct observation of behaviour* ("Seeing someone throw an item in the recycling bin") and *behavioural traces* ("Lights left on in an empty room"). Participants were given feedback and if they answered these comprehension questions incorrectly, they had the chance to revisit the instructions and answer again. Once they passed the comprehension test, participants were shown a random selection of 20 behaviours from a list of 89 pro- and anti-environmental behaviours. For each behaviour, participants could provide as many traces they could think of in a text field provided. Participants were then thanked and debriefed.

[2] Using the search string (("pro*environmental behavio*r*" OR "sustainable behavio*r*" OR "ecological behavio*r*" OR "environmental behavio*r*" OR "green behavio*r*" OR ("behavio*r*" AND "climate")) AND (prevalence OR representative OR public OR household*) AND ("UK" OR "Northern Ireland" OR "Wales" OR "England" OR "Scotland")) on Web of Science (http://webofknowledge.com), which contains articles from more than 20,000 peer-reviewed journals. Date of search: 20/09/2019.

[3] Demographics were not collected for this survey to keep it brief.

1.2. Results

Each of the 89 pro- and anti-environmental behaviours was presented on average to 11 participants (min = 7, max = 15). Participants generated a total of 442 traces, or on average 5.26 traces per behaviour (min = 1, max = 13; pro- and anti-environmental behaviours counted separately).

Traces were excluded if they were exact duplicates (27 responses) or very similar to a trace for a different PEB and thus ambiguous (23) or ambiguous in terms of how many other behaviours not included in the study could have caused it (e.g., "A blanket draped over the sofa in someone else's house" as a trace for the behaviour "Bought or built a traditional home"; 50). Traces were also excluded if they tended to be too private (e.g., "A high energy bill"; 68) or otherwise hard to know about (e.g., "Items past sell-by date in a shared fridge/shared pantry"; 59). Traces mediated by a third party in response to others' behaviour, such as the selection of options (e.g., "Meat options in restaurants and cafés", 37) as well as labels (e.g., "A 'suitable for vegetarians' label on a product", 9) were also excluded. This is because these 'mediated traces' are not direct evidence of individuals' behaviour.

This procedure reduced the number of unique traces to 66. Behaviours and the numbers of associated traces generated (plus reasons for exclusions) can be found in the Supplementary Materials. In the final list, 36 of the initial behaviours had at least one unique trace (23 pro- and 13 anti-environmental behaviours). Most of the final behaviours were linked to one unique trace (median = 1, min = 1, max = 4). The item with the most traces was "Takes train or car for holidays or leisure trips instead of flying (this excludes travelling for work)" (4 traces), followed by "Bought or built an energy-efficient home (e.g. passive house)", "Frequently buys new items (e.g., clothes, luxury items)", "Runs air-conditioning", and "Takes part in a campaign or protest about an environmental issue" (3 traces each).

1.3. Discussion

Participants generated on average one behavioural trace for each of the previously identified PEBs and their related anti-environmental behaviours. Fifty-three behaviours had no unique, unambiguous trace. These behaviours may leave a trace, but it is difficult to distinguish it from the traces created by other behaviours. For instance, a trace identified for the behaviour "Avoids buying new things (e.g., clothes, luxury items)" was "Others' shoes and clothes looked worn-out, e.g., threads, pillings, fading colours". This trace, however, could have alternative causing behaviours, such as the person being careless with their belongings. The results suggest that just as some PEBs are more visible than others (Brick et al., 2017), there are also differences in the visibility of behavioural traces. Future research could investigate whether there is a link between the visibility of traces and the likelihood of people engaging in the related PEBs, that is whether people decide to (not) engage in PEBs based on whether their own traces are visible, as has been found for the visibility of PEBs themselves (Brick et al., 2017; Griskevicius et al., 2010).

2. Survey 2 - Frequency of behaviours and behavioural traces

The main goal of Survey 2 was to understand how frequently the behavioural traces generated from Survey 1 are observed, and whether there is a relation between observing traces and conducting PEBs. For the individual, PEBs constitute a social dilemma where one's contribution is negligible and only many acts of, for instance, energy saving behaviours, can have a meaningful, global impact. A large proportion of people behave as conditional cooperators in social dilemmas (Fischbacher et al., 2001), meaning that they are likely to cooperate on issues that require collective action, provided they know or at least believe that others cooperate as well (Komorita & Parks, 1996). This conditional cooperation strategy is evolutionary very stable because it cannot easily

be exploited by uncooperative others, while being very successful when encountering cooperative others (Axelrod & Hamilton, 1981). Behavioural traces can deliver information on whether others cooperate, that is, behave pro-environmentally. In this context it is secondary whether many of these energy saving acts are performed by a small group, or whether a large group performs some acts. What is important is the overall frequency. Here we thus ask how often behavioural traces are encountered as a measure of how many times PEBs had been performed by others. We hypothesise that observing more behavioural traces of a behaviour makes it more likely that someone engages in the behaviour as well, since this increases the chances that together these acts amount to meaningful impact.

2.1. Methods

2.1.1. Participants

Previous studies (Bergquist et al., 2019) had found an effect size of $d = .59$ from traces to behaviour. This equates to a correlation coefficient of $r = .28$ (Ruscio, 2008). Taking a smaller effect of $r = .20$, we would need to collect $N = 259$ participants with a type I error rate of $\alpha = 0.05$ and power $1 - \beta = .90$. Since we were looking at many correlations in this cross-sectional design, we increased the sample to the maximum number founds allowed, while at the same time using statistical procedures that reduced the possibility of false-positive findings (for details see below).

In total, 806 participants completed the online survey (Age $M = 39.40$; $SD = 17.23$, 51.86% female, 75.95% white ethnicity). Participants were recruited as a representative UK sample via Prolific (www.prolific.co; Palan & Schitter, 2018) and received payments of £1.25. A non-representative subset of 162 participants (Age $M = 19.70$; $SD = 5.72$, 55.56% female) also answered open questions and received £2.00. The survey was approved by the UCL Research Ethics Committee.

2.2. Materials

Traces questionnaire. This questionnaire included 66 traces identified in Survey 1 (Supplementary Materials, Table 4). Participants were asked how often they had noticed the relevant trace in the past three months on a scale from 'Never' (1), 'Not in the last three months' (2), 'Once or twice' (3), 'About monthly' (4), 'About weekly' (5), 'Several times a week' (6), to 'About daily' (7).

Behaviours questionnaire. In total, 36 behaviours corresponded to the 66 traces described in Survey 1 and constituted this questionnaire. Both pro- and anti-environmental behaviours were represented (Supplementary Materials, Table 3). Participants were asked how often they typically engage in the behaviour, on a scale from 'Never' (1), 'Rarely' (2), 'Sometimes' (3), 'Often' (4), to 'Always' (5).

In-/decrease of behaviour. A smaller subset of participants were asked two open-ended questions about when seeing traces made them increase or decrease the frequency of their behaviour: "Please give specific examples of when seeing traces increased (decreased) your own behaviour, i.e., because you saw traces, you did something more (less) often". They were also asked two questions about whether they thought that seeing *frequent* traces *less* often, or *infrequent* traces *more* often, would change their behaviour: "From the list of traces, think of traces that you see daily or almost daily. Do you think that if you never saw them again it would change your behaviour?" and "From the list of traces, think of traces that you have never seen before. Do you think that if you suddenly saw them daily it would change your behaviour?". They were then asked "Would you do the related behaviour …" and could answer with a slider from 'less often' (0) to 'more often' (100). The slider was set to 50 by default.

2.2.1. Procedure

The survey was hosted on Gorilla (www.gorilla.sc; Anwyl-Irvine et al., 2020). After the aim of the study had been explained, participants were asked for their consent. They then answered the frequency of behaviours and the frequency of traces questionnaires. Order of presentation of the two questionnaires was randomised and counterbalanced. Presentation of items within questionnaires was also randomised. In the last section, a subset of participants were additionally asked the open-ended and rating questions about in-/or decrease of their behaviour. All participants were then thanked and debriefed, after which they had the chance to leave any comments.

2.2.2. Data analysis

A Gaussian Markov random field model (Epskamp et al., 2018) was used to estimate a network of the relations between frequency of behaviours and traces. The network is based on partial polychoric correlations using 'least absolute shrinkage and selection operator' (LASSO) regularisation. This means that the total sum of absolute parameter values is limited. Therefore, some parameters are forced to zero and subsequently drop out of the model. The threshold for this is set through the Extended Bayesian Information Criterion (EBIC) hyperparameter γ. EBIC is typically set between 0 and 0.5, with higher values favouring a more sparse network (Foygel & Drton, 2010). We selected $\gamma = 0.5$ with the goal of obtaining a simple model and minimising the risk of false positives. In addition to edges, we report the centrality of behaviours and traces using 'node strength', which is calculated by summing the absolute edge weights for that node. This is more reliable then other centrality measures such as betweenness (Epskamp et al., 2018). Finally, the accuracy of the edges and strengths are estimated using non-parametric bootstrapping ($n = 1000$) whereby data are resampled with replacement and confidence intervals of the partial correlations can be calculated (Epskamp et al., 2018). The network analysis is conducted with R packages *bootnet* (Epskamp et al., 2018) and *qgraph* (Epskamp et al., 2012), and illustrated using *igraph* (Csardi & Nepusz, 2006).

2.3. Results

2.3.1. Frequency of behaviours

Out of the 36 pro- and anti-environmental behaviours presented, the three reported as most frequently performed were 'Recycle items that can be recycled (e.g., glass, paper, plastic, aluminium)', $M = 4.40$, $SD = 4.42$, 'Try not to waste food (e.g. by using leftovers)', $M = 4.30$, $SD = 4.29$, and 'Shop or order things online', $M = 3.70$, $SD = 3.70$[4]; the three least frequently performed behaviours were 'Drive an electric car', $M = 1.10$, $SD = 1.13$, 'Discourage other people from being more pro-environmental (R)',[5] $M = 1.30$, $SD = 1.32$, and 'Cycle to school, university or work', $M = 1.50$, $SD = 1.55$. All behaviours and mean frequencies are presented in Supplementary Materials, Table 3.

2.3.2. Frequency of traces

On average, each trace is observed monthly, $M = 3.90$, $SD = 1$. The three traces reported as most frequently observed (i.e., several times a week) were "A car parked outside school, university, work or shops (R)", $M = 6.20$, $SD = 1.30$, "A delivery van outside someone's home", $M = 5.90$, $SD = 1.22$, and "The car brand or logo of a petrol or diesel car (R)", $M = 5.70$, $SD = 1.75$. The three traces reported as observed least frequently (i.e., not in the last three months) were "Torn-up flyers about a pro-environmental campaign (R)", $M = 1.90$, $SD = 1.27$, "Books and magazines about energy efficient building", $M = 2.30$, $SD = 1.40$, and "A warm floor from radiant floor heating", $M = 2.40$, $SD = 1.49$. All

[4] Online shopping was long seen to be more pro-environmental as it was compared to individual (driving) trips for that item. However, the surge of online shopping in combination with quick delivery promises means that online shopping has higher impact than brick-and-mortar shopping, especially when this would be on-route to/from work or by more environmental means, such as public transport, cycling or walking (Weideli, 2013).

[5] "(R)" refers to a reversed, or anti-environmental, item.

traces and mean frequencies are presented in Supplementary Materials, Table 4.

2.3.3. Co-occurrence of behaviours and traces

A partial correlations network of PEBs and their traces (green nodes) and anti-environmental behaviours and their traces (yellow nodes) is visualised in Fig. 1.[6] The network shows one larger cluster of behaviours around household behaviours (the use of 'green' products, reduced water use and packaging, and recycling correlate) and around activism behaviours (learn about climate change, campaign, donate and engage in an environmental scheme). There are some smaller clusters, for instance around transport (people who cycle or walk are less likely to drive, *et vice versa*) and around improving the energy efficiency of one's home (install insulation and a more efficient heating system, replace an appliance with a more efficient one).

Connections between observing traces of others' behaviours and engaging in behaviours can also be observed in a number of instances (see Table ??). One of the strongest connections is between noticing the trace "A conventional light bulb visible in the fitting (R)" and the behaviour "Use conventional light bulbs (R)", $r = 32$, which is positive; yet noticing "An energy-efficient light bulb visible in the fitting" correlates negatively with the same behaviour, $r = -.13$. The second strongest connection is between the trace "That a radiator is switched on when no one is using the room (R)" and the behaviour "Leave the heating on in a room you're not using (R)", $r = .20$.

In most cases the correlations between traces and behaviours are positive. That is, in general seeing a pro-environmental trace correlates positively with engaging in a (related) PEB and negatively with engaging in a (related) anti-environmental behaviour. The only exceptions to this are that people who likely notice "A large suitcase on a train" (a pro-environmental trace), are also more likely to "Take a plane for holidays and leisure trips (not counting flying for work) (R)" (an anti-environmental behaviour), and that people who likely notice "A caravan or motor home" (a pro-environmental trace), are also more likely to "Drive for shopping and other errands (R)" (an anti-environmental behaviour).

The network also shows that links among traces and links among behaviours are more likely to occur, respectively, than *between* traces and behaviours. Fig. 4 shows *node strength* and their 95% confidence intervals as a measure of centrality for behaviours and traces. High centrality means that these nodes are well connected with other behaviours and traces—if a person engages in this behaviour or notices that trace, they are also more likely to engage in other behaviours and see other traces. For instance, reducing water usage or taking part in an environmental scheme or using 'green' products means that it is likely this person also takes other pro-environmental actions. Nodes of high centrality could therefore be leverage points for interventions, in order to increase overall pro-environmental engagement. Traces are generally more connected than behaviours, which tend to cluster in small groups instead. Traces could thus be leverage points.

For instance, people who see the trace "Social media posts about or likes of articles about sustainability and climate change", are more likely to "Educate yourself about topics related to sustainability and climate change". Once they do this, they are also more likely to engage in other, related PEBs, such as "Do something together with others to address an environmental issue (e.g., set up recycling scheme)", "Donate or invest money in a pro-environmental project", and "Buy an environmentally friendly product (e.g. 'green' cleaning products, organic cotton)" (see Fig. 2).

But the reverse also applies: People who rarely see the trace "Water still left in a shared kettle after use (R)", are more likely to "Boil only the amount of water you need (e.g., when using a kettle or cooking)". Engaging in this specific water-conserving behaviour, they are also more likely to engage in other, related PEBs, such as general "Takes steps to reduce water use", and "Try not to waste food (e.g. by using leftovers)", but they are also less likely to "Leave the lights on in a room you're not using (R)" or "Leave the heating on in a room you're not using (R)" (see Fig. 3).

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2.3.4. Subjective impact of behavioural traces

A subset of the 162 participants answered additional questions related to the subjective impact of behavioural traces. On average, participants reported that if they never saw a currently frequent trace again, it would likely not affect their behaviour, $M = 48.20$, $SD = 23.99$; on a scale from 0 (less often) to 100 (more often). However, if they were to see a currently infrequent trace daily in the future, participants reported they would likely engage in the related behaviour more often, $M = 59.60$, $SD = 22.81$.

When asked about a specific example of when seeing a trace actually decreased or increased their behaviour, the most frequently mentioned trace was "(Images of) plastic in the environment (e.g., oceans)" with 16 mentions. This influenced a number of behaviours, including "Use reusable shopping bag/Avoid single-use plastic bags" (5 mentions), "Recycle more" (4), "Use reusable products/Avoid disposable products" (4), "Avoid plastics" (2), and specifically "Use reusable water bottle" (1). The second most frequent traces were "Dedicated recycling bins" and "Littering", both with 14 mentions, respectively. The former trace led to "Recycle more" (14). The latter trace mainly meant that people "Don't litter" (8), "Avoid disposable cups/Avoid plastics/Avoid single-use plastic bags/Use reusable water bottle" (4) and finally also "Recycle more" (2). Also often reported are the traces "Lights on" (11) and "Reusable shopping bag" (11).

The behaviour reported most frequently as having de-/increased, "Recycle more" (35), is mainly triggered by the presence of "Dedicated recycling bins" (14). The second most frequently reported item, "Turn off lights" (18), is mainly caused by "Lights on" (11) but also by "Lights off (1)".

In general, a PEB was more likely to *increase* (61.74%) than decrease (38.26%) if the trace was pro-environmental. But when the trace was

[6] Exact item wording can be found in the Supplementary Materials.

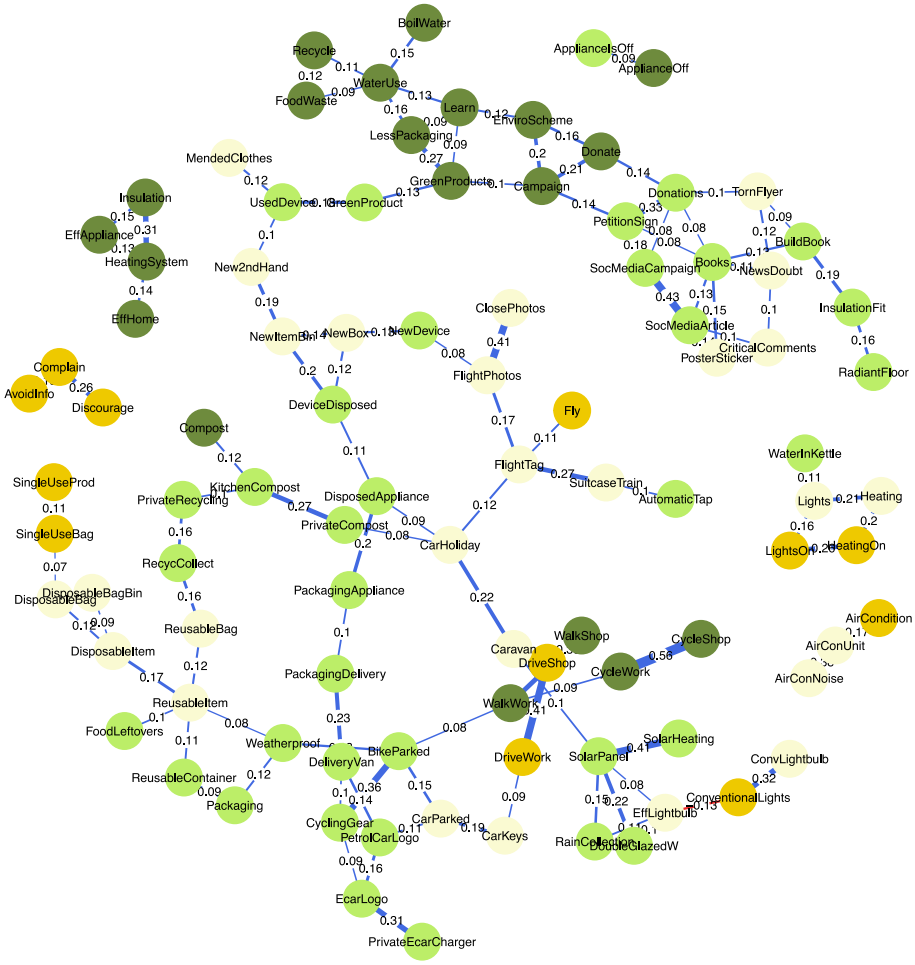

Fig. 1. Correlation network of pro-environmental behaviours (light green), anti-environmental behaviours (dark green), pro-environmental traces (light yellow) and anti-environmental traces (dark yellow). Positive partial correlation are depicted as blue edges and negative partial correlations as red edges and only shown if they are significant at $p < .001$ level. Nodes are placed close to each other when there is a significant correlation, otherwise placement is random.

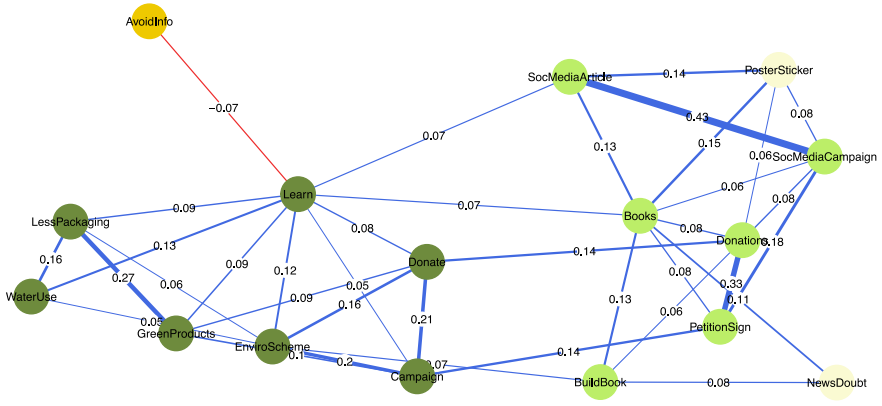

Fig. 2. Zoom into the partial correlations network for the relation between trace 'Social media posts about or likes of articles about sustainability and climate change' (SocMediaArticle) and behaviour 'Educate yourself about topics related to sustainability and climate change' (Learn) and their significant first-order connections.

anti-environmental, the related behaviour is more likely to *decrease* (65.71%) than increase (34.29%). This difference between de-/increase of behaviour and type of trace is significant, χ^2 (1) = 12.05, p = .001, showing that trace and behaviour are aligned: More pro-environmental traces mean an increase in pro-environmental behaviours, more anti-environmental traces mean a decrease in pro-environmental behaviours.

2.4. Discussion

Not previously investigated, there is substantial variability in whether behavioural traces are noticed, ranging between 'Daily' to 'Never before'. The patterns of relations between behaviours and traces determined in the network analysis make intuitive sense. For instance, a cluster emerged around travel habits, where modes of travel correlate

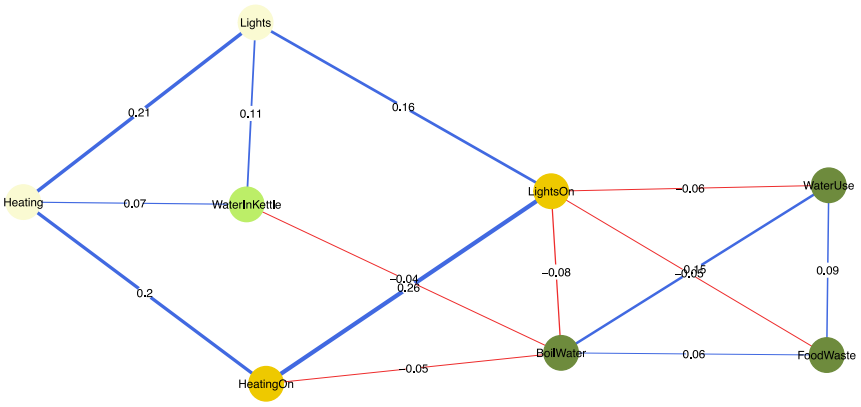

Fig. 3. Zoom into the partial correlations network for the relation between trace 'Water still left in a shared kettle after use (R)' (WaterInKettle) and behaviour 'Boil only the amount of water you need' (BoilWater) and their significant first-order connections.

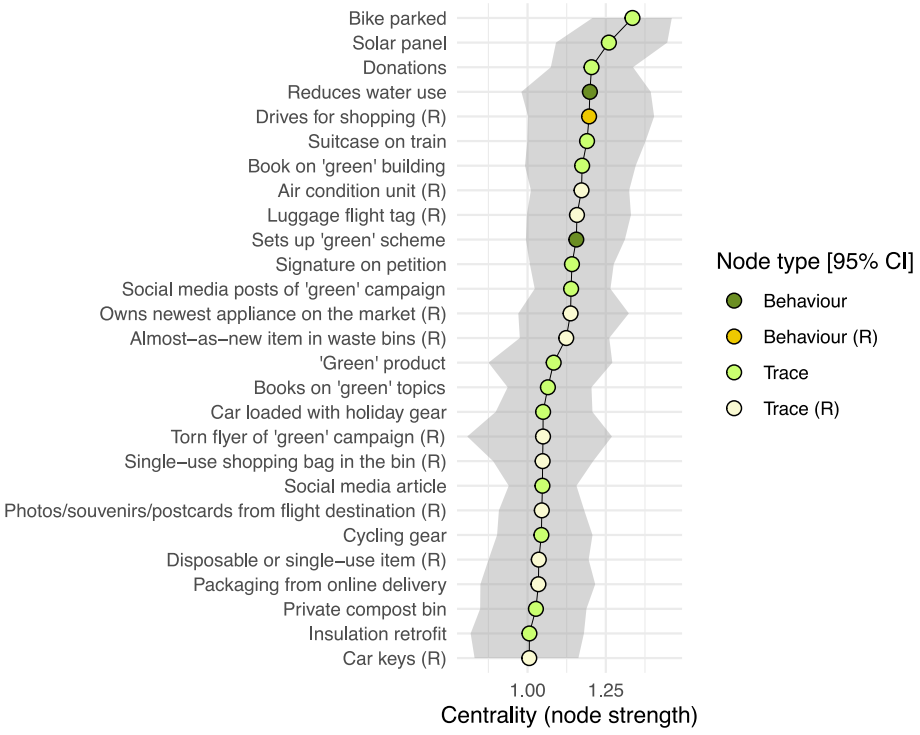

Fig. 4. Pro- (dark green) and anti-environmental (dark yellow) behaviours, as well as pro- (light green) and anti-environmental (light yellow) traces with centrality (node strength or 'connectedness') greater or equal to 1, with 95-percent confidence intervals (grey area).

positively if they are both pro- or both anti-environmental but negatively if they are opposites. Other clusters can be seen around home improvements to be more energy efficient, and around pro-environmental activism. According to participants' reports, a PEB was more likely to *increase* with noticing a pro-environmental trace and more likely to decrease if the trace was anti-environmental.

There are three interesting results to highlight from Survey 2. Firstly, there were correlations among behaviours that tend to be relatively easy, such as recycling, reduced water usage, or boiling only as much water as needed, and correlations among more difficult or 'committed' behaviours (such as substantial changes to one's home), but also some overlap between these, particularly between using 'green' products and campaigning. This lends some evidence to general behavioural 'positive spillover' (i.e., an increased likelihood of engaging in one PEB after having engaged in another; Thøgersen, 2012). Previous findings on positive spillover for PEBs are mixed (Nash et al., 2017). Potential pathways for positive spillover could be that PEBs (a) serve a common goal; (b) influence someone towards a 'greener' self-perception; (c) cause cognitive dissonance; or (d) increase learning about environmental issues. The findings also lend evidence specifically to spillover from 'easier' to 'harder' behaviours, which has been observed before and appears to be mediated by perceived self-efficacy (Lauren et al., 2016). But the question remains why a person starts with one of these behaviours in the first place. Centrality can provide some clues to this as behaviours with more connections may be 'entry behaviours' from which other behaviours follow. This also raises the question whether observation of traces can be entry points—that is, whether observing a trace of a behaviour makes engagement in this behaviour more likely. As our data is cross-sectional, this cannot be answered. However, subjective reports of participants suggests that the causal direction is from traces to behaviours, rather than from behaviours to traces. This is also substantiated by traces having (at least numerically) higher indices of

centrality, meaning that, on average, noticing a trace makes it more likely that other traces are observed *and* behaviours are engaged in, rather than the other way round.

Secondly, the second most frequently reported behaviour "Turn off lights", is mainly caused by "Lights on" but also by "Lights off". This is in contrast to previous studies that looked at how likely it is that people leave the lights on (off) depending on whether they were on (off) before entering a room (Bergquist & Nilsson, 2016; Dwyer et al., 2015; Oceja & Berenguer, 2009). Here the opposite is reported: Lights that are left on prompt participants to switch them off. This may indicate that people are not always aware of when or how they are influenced by behavioural traces. Perception of behavioural traces may be "more automatized … and thus result in corresponding behaviors with less conscious processing" (Bergquist et al., 2019, p. 13).

Finally, all partial correlations between traces were positive. In other words, noticing any trace (either pro- or anti-environmental) makes it more likely to notice other traces. This could be an effect of individual differences in attention: There is considerable and significant variation between individuals with regards to whether moving/touched objects are attended to (De Haas et al., 2019), with the implication that some people may be more prone to attend to behavioural traces than others. Again, people may not be aware of this tendency. This lack of awareness is not necessarily a 'bad' thing: For one, not having to actively seek and perceive traces may be an advantage to coordinate more effortlessly (Parunak, 2005). Also, reactions to behavioural traces may be "driven by nonconscious imitation" and are therefore "less susceptible to anti-conformity and reactance" because "people are less likely to identify a sender" (Bergquist et al., 2019, p. 3). As one participant wrote: "if [I] see people [I] dislike doing something, it makes me much less likely to do it myself". Traces are generally divorced from social appearance; they do not carry the type of information enabling the observer to decide whether one likes or dislikes the person causing it. Behavioural traces are thus arguably more effective than direct communication, especially when created as a by-product of a PEB (so-called *sematectonic traces*; Dipple et al., 2014; Marsh & Onof, 2008).

3. Survey 3 - inferring behaviours from behavioural traces

A behavioural trace (e.g., a bike parked outside a building) offers an opportunity to act in a certain way (e.g. cycle to work or school), particularly if the constituting behaviour can be inferred when confronted with just the behavioural trace. This is especially true for new or uncommon behaviours—which PEBs often are. Also, one and the same trace can in theory have been produced by different circumstances (e.g., many blankets in someone's home could be an indicator that the house is badly insulated, or it could be an interior design choice). The goal of Survey 3 was thus to (a) determine whether people could infer the constituting behaviour just from knowing the trace, as well as (b) which motivations they suspected behind the most likely behaviour they inferred. Being able to infer the behaviour and the reasons behind the behaviour makes it easier for people to choose to engage in this behaviour as well.[7]

3.1. Methods

3.1.1. Participants

A total of 35 participants were recruited from Prolific. All participants were UK residents (62% female, age $M = 38$, $SD = 13.05$), and received £0.15 for participation and a bonus of £0.05 for each meaningful response to open-ended questions. The survey had approval from the UCL Research Ethics Committee.

3.1.2. Materials

We used the same behavioural traces presented in Surveys 1 and 2.

3.1.3. Procedure

The survey was hosted on Qualtrics (www.qualtrics.com) and presented in two parts. In the first part, a trace, described as 'evidence of behaviour', was displayed one at a time and participants were asked to list up to three realistic behaviours that could have caused this trace. In the second part, the trace was displayed again, this time with the causing behaviour participants had entered in the first part. Then participants were asked to give a realistic reason why someone would engage in this behaviour. The exact wording for the instructions are in the Supplementary Materials. Upon completion, participants were thanked and debriefed.

3.1.4. Data analysis

The open field answers were coded as '*corresponds*' if they matched the behaviour they initially referred to, '*corresponds in principle*' if the participant did not directly mention the behaviour but the idea behind it, or '*does not correspond*' if it referred to an entirely different behaviour. For instance, the behaviour "Uses disposable products (e.g., paper/plastic/styrofoam mugs, food containers, cutlery, …)" was presented as the trace "A disposable or single-use item such as a paper mug or a plastic take-out container". A *corresponds* answer might be "Someone has purchased a take-away coffee from a coffee shop", a *does not correspond* answer might be "The container could have been re-used and washed up", and an answer that *corresponds in principle* might be "A demand was created for a take-away item". The first author rated all items; a group of five additional raters categorised a fifth of the items each. There was disagreement in 45.90% cases; this is a combination of 7% cases where one rater said '*corresponds*' and the other '*does not correspond*', 16.50% cases were one said it '*corresponds*' and the other that it '*corresponds in principle*', and 21.30% cases were one said it '*does not correspond*' and the other that it '*corresponds in principle*'. Where there were discrepancies in the rating, the remaining four raters voted independently for one of the two ratings. Most cases were resolved this way with 8.50% that could not be agreed upon; these were excluded from analysis.

Reasons generated for the behaviours were rated by both authors. A coding scheme was devised for external (physical, social, chance) and internal (altruism, self-interest, cognition, emotions) reasons, inspired by previous literature (Kollmuss & Agyeman, 2002; Li et al., 2019). Subthemes were recorded as they emerged from the data by the first author and employed during coding by the second author. If several reasons were given, only the first was recorded (e.g., 'money saving' for the reason given 'It's cheaper/healthier/better for the environment than bus/car'). Agreement rate between first and second rater was at 88.50%. Where there was disagreement, four additional raters voted independently for one of the two ratings which left 3.40% of reasons where no coding could be agreed upon; again, these were not included in the analysis.

3.2. Results

3.2.1. Inference of behaviours from traces

In Survey 3, participants provided 516 possible causing behaviours for the traces presented to them. Of those, 20 were only one-word responses or short phrases that did not clearly refer to a behaviour and were thus excluded. Although we aimed to obtain an equal number of responses for all traces, this was complicated by the fact that some people returned the survey unanswered and participants were not required to answer all (or even any) items. Each trace received between 4 and 11 responses.

[7] Note, however, that this does not apply to all behaviours. For instance, a route that has often been walked (the behaviour) will show a path (trace). The path will often be easier to walk for newcomers than the surrounding high meadow, independent of whether they can infer the causing behaviour or the motivation behind the behaviour.

Of all responses, 128 (24.80%) were rated as *corresponds* to the behaviour, 139 (26.90%) were rated as *corresponds in principle*, and 205 (39.70%) were classified as *does not correspond*. Although all behaviours were coded as *corresponds in principle* at least once, a total of 14 traces had no behaviour that was rated as *corresponds*. Two traces were always recognised as produced by the initial behaviour, these were "Double or treble glazed windows in someone's home" and "An appliance that is unplugged when not in use (e.g. stand-by light is off, room is quiet)". Full results can be found in the Supplementary Materials.

As expected, the order of the answers mattered. In a multinomial logistic regression that uses *does not correspond* as the baseline category, both *corresponds*, $z = 6.33$, $p < .001$, and *corresponds in principle*, $z = 4.32$, $p < .001$, were more likely than *does not correspond* as the first answer compared to the remaining answers. They are, however, no more likely than *does not correspond* as the second compared with the third answer, with $z = 0.70$, $p = .481$ for *corresponds* and $z = 1.53$, $p = .127$ for *corresponds in principle*, respectively. This means that the original behaviour is likely to be the first that comes to mind, compared to possible alternative behaviours.

3.2.2. Inference of reasons for behaviours from traces

Participants reported 137 reasons for why the behaviours they inferred from the traces were performed. We analysed only the 87 reasons for behaviours rated as *corresponds* or *corresponds in principle*. Table ?? lists the frequency of themes and sub-themes for external and internal reasons, respectively. Internal reasons are mentioned more often (79.31%) than external reasons (17.20%). Overall, the most frequent reason is 'Altruism: Benefit climate/environment' (21.80%), followed by 'Self-interest: Money saving' (20.70%), with a shared third place for 'Self-interest: Convenience/avoid effort' and 'Self-interest: Enjoyment' (6.90% each). A closer look shows that all 'Benefit climate/environment' were in response to pro-environmental behaviours (100%). 'Money saving', in contrast, was given as a reason for both pro- (29.30%) and anti-environmental behaviours (13.80%).

3.3. Discussion

All behaviours could at least in principle be inferred from the presented behavioural traces. As can be expected, *corresponds* and *corresponds in principle* ratings were more frequent than *does not correspond* among first responses compared to second and third responses. However, we do not know *how strongly* people endorsed the behaviours they generated. Another study could follow up on this, presenting the trace and letting people rate various possible behaviours (including the original behaviour and behaviours generated from this survey alongside decoys). Interestingly, despite 60.5% of the original behaviours being pro-environmental, only 21.8% of the behaviours generated were explained through a motivation to protect the environment. That is, although people could generally infer the behaviour from the trace, they did not always infer pro-environmental motives as being behind the behaviour. In the absence of knowledge about the actor, people may project their own motives onto others (Malle, 2011). If this is the case, self-interested benefits such as 'money saving' are an important motivator behind PEBs in our sample. Self-interest and altruism can both increase the motivation to engage in PEBs depending on individual motives and may thus be complementary pathways to increased PEBs (De Dominicis et al., 2017).

4. General discussion

To the best of our knowledge, this is the first study to comprehensively investigate behavioural traces for a large number of PEBs. We showed that behavioural traces exist for a wide range of pro- and anti-environmental behaviours and people are generally able to infer the causing behaviour when presented with the trace. Many of the traces are encountered within the last three months, and on average monthly. Noticing certain traces made people more likely to notice other traces as well. There are positive relations between encountering a trace and engaging in a related behaviour for a number of areas in everyday life so that noticing a trace increases the likelihood of the behaviour occurring *et vice versa*.

There are a number of cognitive biases that influence whether someone behaves pro-environmentally, such as *discounting the future* (e.g., foregoing future benefits of home insulation due to current costs, even though the cumulative benefits outweigh in the long run) or *positive illusions* (i.e., the tendency to see the future in a more positive light than is objectively warranted, thus abstaining from mitigating action; Shu & Bazerman, 2010). Some of these biases may be mitigated by the presence of behavioural traces and could explain why observing a trace increases the odds of engaging in the related behaviour. Gifford and Nilsson (2014) for instance highlight the *false consensus effect*, whereby people who strive to maximise their gains at the environment's expense are more likely to believe that others will do the same (Gifford & Hine, 1997). This cognitive bias is harder to maintain in the presence of evidence of others engagement in PEBs. With behavioural traces of PEBs present, it may be harder to (falsely) believe that others share one's intentions, perhaps prompting the actor to reconsider their selfish choices. Similarly, the *self-serving bias* (or *egocentrism bias*; Shu & Bazerman, 2010) leads us to take credit for any good we do (e.g., behave pro-environmentally) but deny any blame for the bad we do (e.g., behave anti-environmentally)—or at least take more credit and less blame than we grant others (*reversed actor-observer effect*; Gifford & Nilsson, 2014). However, we may find it harder to make excuses for our anti-environmental choices when confronted with the hard evidence of our choices such as behavioural traces of our own actions, making it less likely that the self-serving bias is maintained. Nevertheless, the possible effect of behavioural traces may still be undermined by the *negative footprint illusion*: when a 'green' choice is offered in addition to other options, the total footprint is perceived as lower, even though in fact it must be higher because of the additional, albeit 'green', item (Holmgren et al., 2018). However, the results stem from a study using vignettes and may be different with concrete items. It is thus vital that future studies not only investigate the cognitions involved when encountering behavioural traces, but study actual behavioural traces 'in the wild'.

4.1. Limitations and future directions

One intentional limitation is that we only report substantial effect sizes so that results of the network analysis are conservative and should not include many false positives. It is thus possible that we missed existing relations between behaviours and traces. Focussing on only a small set of behaviours and their traces, as well as experimental setups in- or decreasing the number of traces and observing their impact on behaviours, may be needed to get a fuller picture of the direction and strength of these relations.

The initial selection of PEBs was chosen to portray behaviours previously considered as important, but this may have neglected behaviours that have recently increased in importance or were overlooked in the past. Additional behaviours and their traces should be considered in future research. Similarly, half of the sample in Survey 1 were recruited from a student population. Although many mentions of traces were excluded as duplicates, leading us to think we reached a saturation point for the behaviours considered, a sample drawn from a different context may have delivered additional unique traces. Since this study focused on traces in the UK, understanding which behaviours link to which traces would need to be repeated in different countries.

Many studies regarding PEBs—including the present—rely on self-report measures. These are not entirely reliable—only 79% of variance in actual behaviour is explained by self-report measures (Kormos & Gifford, 2014). In addition, people may overestimate how pro-environmentally they behave compared to others (Bergquist, 2020). Similarly, people may not be able to accurately report behavioural traces

encountered if the measure is, for instance, not immediate and sensitive enough (Newell & Shanks, 2014). It is therefore desirable to use actual behaviour as the outcome measure in future research and, where possible, manipulate or control for features of behavioural traces.

Another limitation of the design of this study is that it does not allow us to draw conclusions about causality. People may already be engaging in the behaviour and as a result encounter other people's traces more often; or, participants may encounter other's traces and therefore explore the behaviour. When asked about their own estimation whether traces would decrease or increase their behaviours, they expect seeing a new trace to increase the related behaviour. By contrast, once a behaviour is adopted, they expect that seeing the related trace never again would have little impact. This indicates that behavioural traces may be a source of learning about new behaviours, but have little impact on the maintenance of that behaviour. Most likely, the relation between traces and behaviour is a dynamic one that depends on a number of other factors, such as the *frequency*, *number* and *type* of traces encountered. Someone not currently engaging in a behaviour may become aware of the behaviour through traces that are frequent, numerous, or otherwise highly salient. As they start engaging in the behaviour, they would likely encounter related traces even more often, for instance if they start commuting by bicycle and therefore encounter more cycling-related traces. Whilst this is plausible, additional research is required to ascertain the direction of this relation, ideally longitudinally. Alternatively, future research could focus on specific behaviours and their traces in a more controlled design to shed light on the causal direction between traces and behaviours.

Here we focused on how often traces are encountered, ignoring whether many traces were created by few people, or few traces were created by many people. However, it may be interesting to investigate whether the effect of traces is moderated by who created them. For instance, one bike left outside the building every single day in rain, sunshine or snow may signal a different level of commitment compared to many bikes left on sunny days only (the number of commutes by bike and thus energy saved being equal).

4.2. Implications

Widespread adoption of PEBs will be necessary to avert the worst of the climate crisis (Dietz et al., 2009), be that voluntary as bottom-up action or through policy changes as top-down requirements. For the large group of conditional cooperators (Fischbacher et al., 2001), seeing behavioural traces of PEBs could increase their willingness to engage in PEBs themselves. From behavioural traces we cannot know whether a majority creates a few traces, or whether a small but dedicated group creates many traces. Thus behavioural traces provide a less certain picture about what the majority of other people are doing than, for example, the information that 'X% of people engage in behaviour Y'—the way descriptive social norms are often communicated. But perhaps conditional cooperators do not need to know that a *majority* of people engage in PEBs. What counts is the cumulative impact, not the number of contributors, and behavioural traces can capture this information very well. For instance, a hundred lightbulbs being switched off means 100 times savings – it does not matter whether one person switched all of them off or a hundred people switched off one each. In fact, a small dedicated group may even have a higher total impact than a less dedicated majority. Assuming average carbon footprints, the impact one person can make by stopping to fly equals 15 people dedicated to perfect paper recycling (MacKay, 2008). Only knowing the descriptive norms of both behaviours would then actually be detrimental to impactful (conditional) cooperation. Behavioural traces *and* beliefs of descriptive social norms in tandem could of course have an even larger effect on behaviour than each on their own. However, additional research is needed as to when frequent behavioural traces are perceived as a descriptive norm to be able to separate their effects.

Individual action is but one side of the coin, however. Bendor and Mookherjee (1987) demonstrate that although decentralised conditional cooperation (we imagine, for instance, through behavioural traces) is only superior in conditions with perfect information about the relationship between individual actions and collective benefits, decentralised conditional cooperation can nevertheless supplement centralised coordination of collective action. Most likely, new policies will be adopted more quickly if they are introduced when a critical number of people already engage in related behaviours. The near global ban or tax on single-use plastic bags is a case in point (Clapp & Swanston, 2009). While more research is needed to fully understand the relation between behaviours and their traces, we can show that there are meaningful links between noticing a behavioural trace and engagement in related behaviours. In terms of interventions, the following approach may thus be promising: (1) encourage those who already engage in PEBs so that they continue to produce the related traces, and (2) visually highlight or otherwise emphasize the resultant behavioural traces while (3) making anti-environmental traces less salient. Together, this could directly and indirectly increase awareness of the behaviours as well as the number of people engaged in these behaviours.

CRediT author statement

Sabine Topf: Conceptualisation, Methodology, Formal analysis, Data curation, Writing – Original Draft, Project administration. Maarten Speekenbrink: Conceptualisation, Methodology, Writing – Review & Editing, Supervision.

Declaration of competing interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2022.101886.

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