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Empirical Article

Irregular stimulus distribution increases the negative footprint illusion

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As a climate change mitigation strategy, environmentally certified 'green' buildings with low carbon footprints are becoming more prevalent in the world. An interesting psychological question is how people perceive the carbon footprint of these buildings given their spatial distributions in a given community. Here we examine whether regular distribution (i.e., buildings organized in a block) or irregular distribution (i.e., buildings randomly distributed) influences people's perception of the carbon footprint of the communities. We first replicated the negative footprint illusion, the tendency to estimate a lower carbon footprint of a combined group of environmentally certified green buildings and ordinary conventional buildings, than the carbon footprint of the conventional buildings alone. Importantly, we found that irregular distribution of the buildings increased the magnitude of the negative footprint illusion. Potential applied implications for urban planning of green buildings are discussed.

Key words: Negative footprint illusion, perceived numerosity, spatial distribution.

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INTRODUCTION

Previous research has demonstrated an effect called *the negative footprint illusion* (Gorissen & Weijters, 2016), whereby people tend to assign a lower environmental impact estimate to a group of 'green' (relatively environmentally friendly items, such as an 'environmentally certified' building) and ordinary (relatively environmentally unfriendly items, such as a conventional building) items in combination, in comparison with the estimate of the ordinary items alone (for a recent review, see Sörqvist, Colding & Marsh, 2020). The negative footprint illusion is an example of a broader phenomenon of categorization effects, associated with the difference by which the human cognitive system processes two separate sets of items and a unified set comprising these two sets in combination (Chernev & Gal, 2010). The negative footprint illusion has been observed for a diverse range of to-be-estimated items, from the food domain (Gorissen & Weijters, 2016; Kusch & Fiebelkorn, 2019), to vehicles (Kim & Schuldt, 2018) and buildings (Holmgren, Andersson & Sörqvist, 2018; Holmgren, Kabanshi, Marsh & Sörqvist, 2018). The effect thus appears to be fairly robust and replicable and, while it may vary in size depending on the type of stimulus category (food, Gorissen & Weijters, 2016 vs. buildings Holmgren, Kabanshi, *et al.*, 2018), it seems relatively insensitive to the type of to-be-estimated objects. In the present study, we investigate whether another stimulus feature influences the magnitude of the effect. Specifically, we investigate whether the visuo-spatial distribution of the to-be-estimated items can influence the negative footprint illusion by capitalizing on a well-known feature of visual displays: spatial (ir)regularity (Poom, Lindskog, Winman & van den Berg, 2019; Zhao & Yu, 2016).

The majority of previous studies on the negative footprint illusion have focused on the category of to-be-estimated items (e.g., vehicles vs. food products) and dispositional factors (e.g., Holmgren, Kabanshi, *et al.*, 2018; MacCutcheon, Holmgren & Haga, 2020) to the relative expense of the visual presentation of the information for which the judgements are required to be made. This is remiss since these judgements probably entail the perception of information such as numerosity from the stimuli. For example, previous work has shown that numerical information can influence the magnitude of the negative footprint illusion. Preliminary (and as of yet unpublished) work from our laboratories indicates that a larger negative footprint illusion is obtained with high as compared with low quantity of environmentally friendly additions and that the negative footprint illusion is related to the *quantity* of objects even when the ratio between conventional and the added environmentally-friendly is held constant. Larger quantity information may therefore bias individuals to perform averaging over summation thereby accentuating the negative footprint illusion. These recent findings are consistent with an averaging account of the negative footprint illusion whereby people tend to think that the carbon footprint of a combined set of two subsets is the average, rather than the sum, of the carbon footprint of the two subsets (Holmgren, Andersson & Sörqvist, 2018).

The effects attributable to the quantities of conventional and eco-friendly objects may be driven, at least in part, by the operation of the visual system in perceiving information in relation to conventional and eco-friendly objects, such as their number or ratio. The visual system rapidly approximates the number of items within a visual array in the absence of explicit

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Patrik Sörqvist and John E. Marsh contributed equally to the work. The authors declare that there is no conflict of interest.

counting (e.g., Ansari, 2008). This cognitive ability of quantity estimation may be served by a dedicated approximate number system (Dehaene, 1992) that has been advanced to explain the link between human number sense and performance on arithmetic tasks (Chen & Li, 2014). A number of factors has been discovered to influence perceived numerosity. One factor is grouping cues, such as statistical regularities (Zhao & Yu, 2016), shared features and categorical membership (Halberda, Mazzocco & Feigenson, 2008), spatial arrangement (Ginsburg, 1976, 1978), and segmentation (He, Zhang, Zhou & Chen, 2009). Grouping cues influence perceived numerosity and also highlight how objects are related. For example, objects that are connected by line segments are underestimated in comparison with objects that are disconnected (Franconeri, Bemis & Alvarez, 2009; He et al., 2009). Objects that reliably co-occur with each other in space are underestimated compared to objects that appear randomly (Zhao & Yu, 2016). Grouping cues also can influence how attention is directed to the objects in the visual display, thus influencing perceptual organization (Barbot, Liu, Kimichi & Carrasco, 2018).

In the context of the negative footprint illusion, estimating the carbon footprint of additional eco-friendly items may increase visual attention to these eco-friendly items in the visual display and heighten perceptual organization, which can reduce their perceived numerosity. In the typical paradigm of the negative footprint illusion (Holmgren, Andersson & Sörqvist, 2018), the environmentally-friendly objects (usually houses) are spatially clustered and separated from the conventional objects in terms of color and category. When required to make a 'green addition,' visual attention toward the green clustered items may result in unitization of those objects, or make the information more compressible due to redundancies (Brady, Konkle & Alvarez, 2009), thereby giving rise to an under-representation and subsequent underestimation of numerosity.

Given the prior findings on numerosity perception, we hypothesize that the negative footprint illusion should be smaller when both the environmentally-friendly items and conventional items are organized in a regular pattern (as distinct spatial blocks) than when the items are organized in an irregular pattern (environmentally-friendly items randomly interspersed with conventional items). This effect can occur via an underestimation of the number of the clustered environmentally-friendly items compared to the randomly distributed environmentally-friendly items.

METHODS

Participants

The participants were 160 adults (105 female) with a mean age of 23.21 years (SD = 3.67 years). All participants were recruited via the Prolific Academic participant sourcing site (Palan & Schitter, 2018) and received the standard department payment rate in exchange for 5 min of participation time. The 'custom screening' option was chosen with Prolific Academic. Participants were eligible if they indicated that they would participate using a desktop computer. To ensure some control over factors that could influence reasoning and decision-making, the prescreened exclusion criteria included 'student status,' 'dyslexia, dyspraxia, ADHD or any other related literacy difficulties,' 'NHS mental health support,' 'mild

cognitive impairment/dementia,' 'antidepressants,' 'mental illness,' 'daily impact,' 'autistic spectrum disorder' and 'mental health/illness/condition – ongoing.' Further eligibility criteria included self-report of normal or corrected-to-normal vision, 18–30 years of age, UK nationality, born in the UK and speaking English as first language. Finally, participants were only eligible if their approval rate was greater than 95% for participation on Prolific Academic. This was considered as helping to achieve higher quality data. The study received Ethical Clearance from the University of Central Lancashire, Preston, United Kingdom. The data of this study are available as an appendix to this paper in the journal's repository.

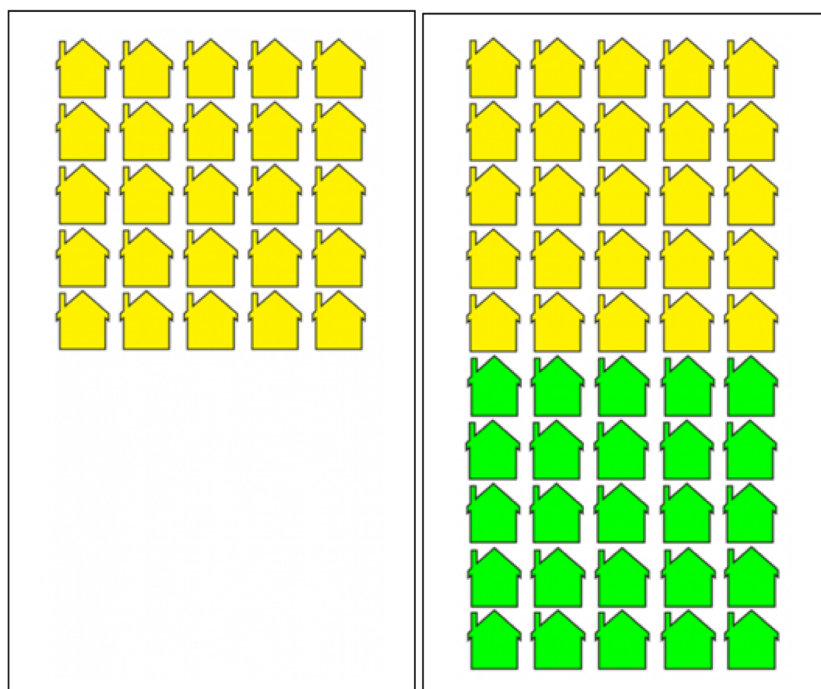## MATERIALS, DESIGN AND PROCEDURE

Stimulus displays

Drawings of green houses were used to represent environmentally-friendly items and drawings of yellow houses were used to represent conventional items in the current study. Each display contained either conventional houses only, or a combination of conventional houses and eco-friendly houses (see Fig. 1). Since stimuli presented on the left are perceived, on average, as more numerous than those presented on the right (Nicholls, Bradshaw & Mattingley, 1999), we ensured that the number of eco-friendly and conventional houses were approximately equal in either side of the central vertical plane. Total stimulus area was identical between the regular and irregular presentation conditions. In the conventional houses only condition, eco-friendly houses were demarked as empty space, such that the conventional houses only occupied half of the stimulus area for the regular and irregular conditions. In the combined houses condition, eco-friendly houses were presented in a block and the conventional houses were presented in an adjacent block in the regular condition, and the two types of houses were randomly interspersed in the irregular condition. Since the goal was to investigate the influence of visual representation notwithstanding the presence of quantities, we retained the same numerosity between the regular and irregular conditions, although the number of houses in the conventional houses only condition was half of that in the combined houses condition.

Our irregular stimulus organization was designed in accordance with work undertaken by Barbot et al. (2018). The stimuli were constructed such that perceptual organization could not function to structure the visual input into perceptually coherent units using grouping and segregation processes (e.g., proximity, similarity, good continuation, closure, common region and element connectedness; Peterson & Kimchi, 2013). We chose 5 × 5 grids in the conventional houses only condition wherein houses from two different types (as indicated by color) were neither organized by column nor by row (see Fig. 1). In the combined houses condition, the disorganized 5 × 5 configuration was replicated to create a 10 × 5 grid to include the green eco-friendly houses. The green eco-friendly houses were removed from the grid to create a conventional only irregular stimulus.

Carbon footprint rating task

Participants were informed that they would be presented with two displays of houses that represented a community. They were
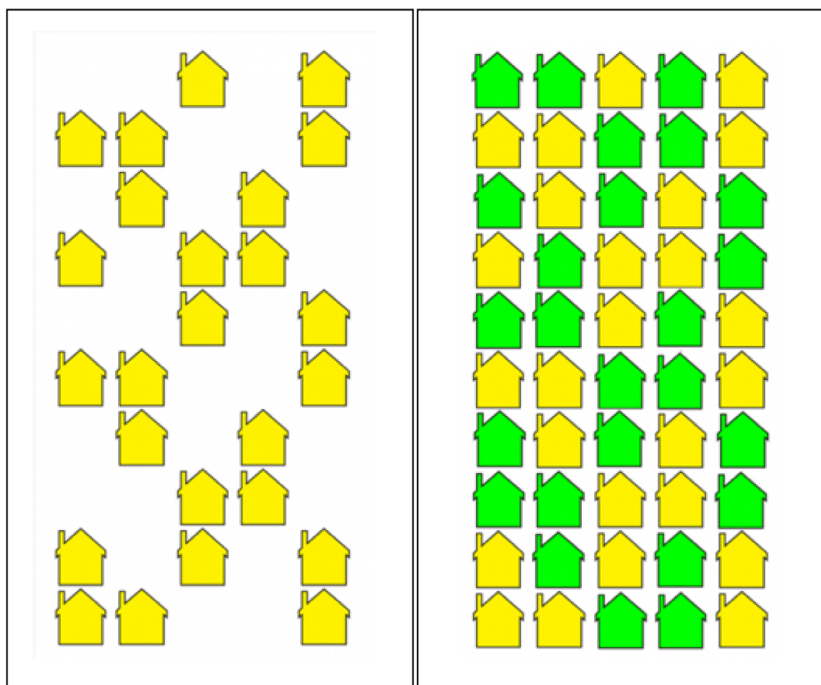
Panel **(a)**

Conventional only items, regularly distributed

Conventional and green items, regularly distributed

Panel **(b)**

Conventional only items, irregularly distributed

Conventional and green items, irregularly distributed

Fig. 1. The figure shows the visual stimulus material used in the four conditions of the experiment. Yellow houses represent 'conventional items' and green houses represent 'environmentally certified/green items.' The items were either presented in a regular fashion (blocked; Panel a) or in an irregular fashion (random; Panel b).

instructed to estimate how large a carbon footprint the houses in each community have in total. Carbon footprint, they were told, refers to the carbon emissions that arise due to, for example, building ventilation, electricity consumption and heating. Furthermore, they were told that a high carbon footprint is worse for the environment whereas a low carbon footprint is better for the environment. Participants were asked to estimate the carbon footprint of each community based on a scale from 1 (low carbon footprint) to 9 (high carbon footprint). As a reference point for their estimates, they were told that a building of 30 conventional apartments would score 5 on the scale.

For the conventional houses only condition, participants were presented with the conventional houses in disorganized configuration in the irregular presentation condition, while participants in the regular presentation condition were presented with the conventional houses in the 5×5 organized configuration (see Fig. 1). In both conditions, participants were asked to provide a rating for the 25 conventional houses that were colored in yellow. Subsequent to making this conventional-only rating, participants were then presented with new information that 25 environmentally certified houses had been built in the same community (combined houses condition). They were told that environmentally-certified houses have low environmental impact and are designed and built using materials and technology that reduces their carbon footprint and lowers their energy requirements. Furthermore, participants were told that these environmentally-certified houses were represented by color green on the display. Accompanying this text instruction, participants in the irregular presentation condition were presented with a 10×5 grid where the eco-friendly, green houses were randomly interspersed with the conventional, yellow houses in a disorganized configuration (see Fig. 1). Participants in the regular presentation condition were, in turn, presented with the initial 5×5 grid of conventional, yellow, houses with an additional 5×5 grid of eco-friendly, green, houses beneath, thereby creating a 10×5 grid where the conventional and eco-friendly houses were perceptually grouped. In both conditions, participants were asked to make a similar estimate as they had done previously and rated how large the carbon footprint was for all houses taken together using the same nine-point scale. Thus, the experiment comprised a 2 (item set: conventional only vs. combined conventional and green) $\times$ 2 (stimulus presentation: irregular vs. regular stimulus presentation) design with item set variable manipulated within participants and the stimulus presentation variable manipulated between participants.

RESULTS

We conducted a 2 (item set: conventional only vs. combined conventional and green, within-subjects) $\times$ 2 (stimulus presentation: irregular vs. regular stimulus presentation, between-subjects) ANOVA on the ratings of carbon footprint. There was a significant interaction between item set and stimulus presentation [$F(1, 158) = 4.09$, $MSE = 1.48$, $p = 0.045$, $\eta^2_p = 0.03$]. The main effect of item set was also significant [$F(1, 158) = 34.61$, $MSE = 1.48$, $p < 0.001$, $\eta^2_p = 0.18$], but the main effect of stimulus presentation was not significant [$F(1, 158) = 3.11$, $MSE = 2.72$, $p = 0.080$, $\eta^2_p = 0.02$]. As Fig. 2 shows, the
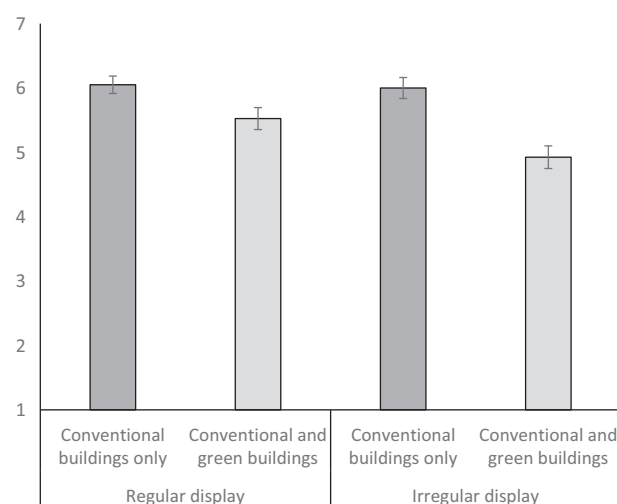

Fig. 2. The carbon footprint ratings (from 1 = low carbon footprint to 9 = high carbon footprint) of conventional and green items presented either in a regular display (blocked stimuli) or an irregular display (randomly distributed stimuli). Error bars represent standard error of means.

negative footprint illusion was found in both the regular presentation condition [$t(79) = 2.87$, $p = 0.005$, $d = 0.32$], and the irregular presentation condition [$t(79) = 5.35$, $p = .001$, $d = 0.55$]. As the interaction indicates, the magnitude of the negative footprint illusion was larger in the irregular presentation condition than in the regular condition (Fig. 2). Thus, the spatial distribution of the to-be-estimated stimuli influences the magnitude of the negative footprint illusion.

DISCUSSION

The purpose of the current study was to examine whether the magnitude of the negative footprint illusion could be modulated by the spatial (ir)regularity of visual stimuli representing conventional objects and the additional environmentally-friendly objects. The negative footprint illusion was stronger when these objects were distributed irregularly across the stimulus display compared to regular presentation whereby the two groups of objects were sorted and spatially separated into two distinct blocks on the display. This enhanced negative footprint illusion manifests even with the explicit presentation of quantity information: Participants were informed of the quantity of conventional (25) and environmentally-certified (25) houses.

In the conventional houses only condition, the total carbon footprint was rated similarly when the houses were randomly distributed or presented in a block. However, in the combined condition, the total carbon footprint was rated as significantly lower when the additional green eco-friendly houses were randomly distributed than when presented in a block (Fig. 2). This suggests that the negative footprint illusion was largely driven by the organization of the green eco-friendly houses, rather than the conventional houses. Since more spread-out objects increase perceived numerosity (Krueger, 1972), participants may have perceived a greater number of green eco-friendly houses in the irregular condition than the regular condition, which could

increase the negative footprint illusion. Another explanation is that the addition of blocked green eco-friendly houses may have drawn attention toward the blocked green houses away from the blocked yellow conventional houses, thereby increasing the perceptual organization of the green houses (Barbot *et al*., 2018), and reducing the perceived numerosity of the green houses in the regular condition. This may contribute to the attenuation of the negative footprint illusion in the regular condition.

Other factors that could affect perceived numerosity include symmetry, total stimulus area and individual stimulus size. In the current study, the irregular presentation of houses reduced symmetry relative to the regular presentation. Thus, it is possible that reduced symmetry increased perceived numerosity of the green eco-friendly houses (Apthorp & Bell, 2015; Howe & Jung, 1987). It may be prudent in future studies to more cleanly manipulate the symmetry of the stimulus display. Another future direction is to manipulate stimulus size in the negative footprint illusion domain, which could influence perceived energy use. For example, people tend to rate larger objects as having more energy consumption than smaller objects (Baird & Brier, 1981; Cowen & Gatersleben, 2017). This said, there is mixed evidence on the effect of stimulus size on perceived numerosity, with some studies reporting that larger stimuli are perceived as being in greater number than smaller ones (e.g., Gebuis, Kenemans, de Haan & van der Smagt, 2010; Gilmore, Attridge, Clayton *et al*., 2013) and other studies reporting the opposite (Gebuis & van der Smagt, 2011; Ginsburg, 1976; Ginsburg & Nicholls, 1988).

While the current results indicate that spatial irregularity is a stimulus feature that influences the magnitude of the negative footprint illusion, other stimulus features might also underpin the behavioral outcome. For example, the stimulus color could potentially influence how the participants respond to the carbon footprint rating task. Schuldt (2013) found that people think candy bars are healthier if the bars' nutrition labels are green. Similarly, the green color of the houses of the stimulus displays of the current study might make participants associate the houses with less carbon footprint than what had been the case if a different color had been used. While this stimulus feature might influence the estimates in absolute terms, it should not compromise the difference between the two stimulus regularity conditions reported in the current study because stimulus color was held constant between conditions. Yet, the influence of stimulus features such as color on the negative footprint illusion could be an interesting topic for future research.

In conclusion, the current study demonstrated that visual spatial presentation can influence perceived carbon footprint. Specifically, irregular organization could exacerbate errors in human judgment and decision processes. This finding provides implications for urban planning of green environmentally certified buildings worthy of future research exploration. One situation where this feature of the negative footprint illusion could come into play is in the context of urban planning involving spatially-irregular distributions of green buildings. Environmentally certified buildings have become increasingly prevalent in the last few decades as a solution to reduce carbon emissions and mitigate climate change. According to the annual report of the World Green Building Council, the cumulative building area certified by green building councils has increased by 1,000% in the last

decade from 300 m square meters to 3.5 bn square meters (WGBC, 2020). As green buildings become more popular, an interesting psychological question is how people perceive the environmental impact of these buildings. It is relevant to note, though, that the experimental stimuli used in the study reported here were stylized and not realistic, to the benefit of the internal validity of the experiment but at the cost of the external validity/generalizability.

Our findings also inform future research on the negative footprint illusion about the importance of considering the visuo-spatial features of the to-be-estimated stimuli. Since the spatial distribution of the items influences the magnitude of the effect, features attributable to spatial factors could make the difference between finding the effect and not finding the effect. Hence, spatial factors may partly explain why the negative footprint illusion seems to vary in magnitude depending on stimulus categories (food; Gorissen & Weijters, 2016; compared with buildings; Holmgren, Kabanshi, *et al*., 2018). In other words, differences that appear to be attributable to category-type might be better explained by differences in spatial factors.

DATA AVAILABILITY STATEMENT

The data of this study are available as an appendix to this paper in the journal's repository.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article:

Appendix S1 Supporting Information