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Perceptions of blue-green and grey infrastructure as climate change adaptation strategies for urban water resilience

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Abstract: Blue-Green Infrastructure (BGI, including swales, green roofs, and wetlands) plays an important role in reducing vulnerability to climate change risks such as flooding, heat stress, and water shortages, while enhancing urban environments and quality of life for citizens. Understanding the perceptions that professional stakeholders have of BGI is fundamental in addressing barriers to implementation. A novel application of the Implicit Association Test (IAT) is developed to investigate and compare implicit (unconscious) perceptions of blue-green and grey infrastructure with explicit (conscious) attitudes. This is the first time an IAT about BGI has focused on professional stakeholders. Blue-green and grey infrastructure are perceived positively by the sample population. Overall, respondents implicitly and explicitly prefer BGI to grey infrastructure, and regard it as safer, tidier, more attractive, useful, valuable, and necessary. The individual positive explicit perceptions of grey infrastructure, nonetheless, suggest that integrated blue-green and grey systems may be preferable for professional stakeholders to incorporate into water management and climate change adaptation strategies.

Keywords: Blue-Green Infrastructure, Implicit Association Test, perceptions, grey infrastructure, climate change, adaptation, stakeholders, attitudes, flooding, urban water management.

Notes on the authors: see end of article.

Introduction

Cities around the world face the challenge of adapting to the impacts of climate change, including more frequent and intense rainfall events, droughts, and heatwaves (IPCC 2014, Arnell *et al.* 2016, Guerreiro *et al.* 2018). The sustainable management of water resources is also crucial for urban climate resilience (Özerol *et al.* 2020). The form and function of cities intensifiy climate change impacts (Carter *et al.* 2018): urban development and consequential expansion of hard surfacing, for example, result in the loss of natural blue and green spaces that previously contributed to reducing flood risk through infiltration, attenuation, conveyance, and/or storage (O'Donnell & Thorne 2020). Flooding is a major risk for urban environments: for example, it is the greatest risk to infrastructure in the UK from climate change (Dawson *et al.* 2018). The increase in hydrological extremes seen across the globe as a result of human-induced climate change (Gudmundsson *et al.* 2021) has led to many international cities developing adaptation strategies to reduce the impacts of climate change while maintaining (or enhancing) healthy environments, quality of life for citizens, and economic activity (City of Rotterdam 2013, City of Melbourne 2017, Scottish Government 2019). In the European Union these may include strategies for smart specialisation whereby unique opportunities for development and growth are identified based on assets, resources, and specific socio-economic challenges in different cities, regions, and countries (European Commission 2020), achieving the aim of cohesion policy by promoting a better link between the production of new knowledge stemming from innovation and investment, and its application to new projects and services (D'Adda *et al.* 2020). Climate change adaptation is increasingly framed as an opportunity to improve liveability and well-being in cities (Aylett 2015). Progressively more local governments are including climate resilience within broader goals to improve quality of life in cities (Hölscher *et al.* 2019) and meet the Sustainable Development Goals (SDGs), particularly around good health and well-being (SDG3), clean water and sanitation (SDG6), and sustainable cities and communities (SDG11).

The functionality provided by urban green (and blue) space is increasingly important in a changing climate (Gill *et al.* 2007). Blue-Green Infrastructure (BGI), often referred to in the context of flood and water management, is defined by the use of natural and designed blue and green components to mimic and/or enhance natural hydrological cycle processes of infiltration, evapotranspiration, and reuse (Novotny *et al.* 2010). BGI assets, including swales, rain gardens, green roofs, wetlands, street trees, ponds, and re-naturalised and de-culverted rivers, are designed to turn 'blue' (or 'bluer') during rainfall events in order to reduce urban flood risk. BGI, like Nature-Based Solutions (NBS) and Sustainable Drainage Systems (SuDS), offers a multifunctional approach that can further reduce vulnerability to other climate change risks, such as heat stress, water shortages, and air pollution (Demuzere *et al.* 2014). Despite extensive evidence of the multiple benefits of BGI, and provision of ecosystem services (e.g., Hansen & Pauleit 2014, Fenner 2017, Alves *et al.* 2019a, Paulin *et al.* 2020), a range of institutional, socio-political, and technical barriers limit widespread adoption (Brown & Farrelly 2009, O'Donnell *et al.* 2017).

Understanding the myriad perceptions that professional city stakeholders hold towards different types of BGI in the public realm is fundamental in addressing the socio-political barriers to their implementation and ultimately delivering BGI projects that are accepted, supported, and desired (Suppakittpaisarn *et al.* 2019, O'Donnell *et al.* 2020a). Previous research into the perceptions of BGI has focused on residents and communities living alongside blue-green assets, and typically report stated preferences based on explicit, or self-reported measures such as questionnaires, interviews, and Likert-scale tests (e.g., Hayden *et al.* 2015, Derkzen *et al.* 2017, Wang *et al.* 2017, Everett *et al.* 2018, Williams *et al.* 2019). It is essential to supplement knowledge of public perceptions with an understanding of the attitudes of professionals working with blue-green and grey infrastructure, in order to understand challenges and opportunities, and to identify where changes in research foci, policy, and practice are needed for increased implementation of multifunctional BGI. Furthermore, these experts are trusted to develop BGI projects that deliver multiple benefits beyond urban water management, founded on their perceptions of what constitutes a 'good' design (Suppakittpaisarn *et al.* 2019). The need to understand their preferences, and understand how they may differ from public perceptions, is of paramount importance.

Investigations into the perceptions of blue-green and grey infrastructure held by professional stakeholders, to date, have used explicit measures. As an example, Shandas *et al.* (2019) explored the social, political, and biophysical opportunities and challenges of Green Stormwater Infrastructure (GSI) systems through focus groups with municipal managers in Portland, Oregon, and Clark County, Washington, USA. Miller and Montalto (2019) used a structured online survey to investigate the range of ecosystem services that New York City practitioners attribute to different types of Green Infrastructure (GI), ultimately inferring which types of GI are most desirable to professional stakeholders and why. While designers' and laypeople's preferences for different categories of GSI were found to be similar, Suppakittpaisarn *et al.* (2019) identified significant differences between preferences for bioretention basins and green roofs.

The explicit attitude measures employed in these examples assume that participants know and can articulate their beliefs (Schultz *et al.* 2004) and have an internalised concept of GSI/GI that they consciously base their attitudes on. While we expect professionals working with BGI to be able to articulate their explicit perceptions of blue-green and grey infrastructure, explicit attitude measures are also affected by self-presentation effects—that is, responses that attempt to convey information about oneself or a desired image of oneself to other people (Baumeister & Hutton 1987)—that undermine their validity (Gregg & Klymowsky 2013). Implicit attitude measures that are not consciously controlled (that is, are spontaneous) remove many of the external influences that affect explicit tests (Spence & Townsend 2006), and provide insight into underlying or unspoken attitudes that may diverge from conscious attitudes (Greenwald & Banaji 1995).

The Implicit Association Test (IAT) is widely used to reveal implicit attitudes by measuring the strengths of concept–attribute associations (Greenwald *et al.* 1998). The IAT is a computer-based methodology in which participants sort stimuli into pairings of contrasting target-concepts and evaluative attributes; the response time of different pairings is compared to determine implicit preferences. Participants match stimuli, either words or photographs (for example, Daisy or Caterpillar) with the appropriate concept (for example, Flower or Insect) as quickly as possible. Two concepts are then combined (Flower and Pleasant; Insect and Unpleasant). Implicit attitudes are calculated as the difference between the average response times for compatible trials (Flower and Pleasant; Insect and Unpleasant) and incompatible trials (Flower and Unpleasant; Insect and Pleasant).

Early IATs focused on controversial or sensitive topics, investigating implicit prejudices based on race, religious ethnicity, age, and nationality (e.g., Greenwald *et al.* 1998, Rudman *et al.* 1999). In the field of environmental research, IATs have been used to investigate perceptions of climate change (Beattie & McGuire 2012), nuclear power (Siegrist *et al.* 2006, Truelove *et al.* 2014), implicit connectedness with nature (Schultz *et al.* 2004, Bruni & Schultz 2010, Liu *et al.* 2019), and the influence of extreme weather on voting habits (Rudman *et al.* 2013). Implicit attitudes towards blue-green and grey infrastructure are not yet understood. In a novel application of the IAT, O'Donnell *et al.* (2020a) investigated and compared implicit and explicit perceptions of SuDS in public greenspace, based on a sample population of residents in Newcastle-upon-Tyne, UK (n = 193). Greenspace with and without SuDS were perceived positively by most respondents yet greenspace without SuDS was implicitly and explicitly preferred, and explicitly regarded as more attractive, tidier, and safer.

Study scope and rationale

In this paper, we investigate and compare implicit and explicit perceptions of blue-green and grey infrastructure, measured by an IAT and feeling thermometers,[1] respectively, of professionals with expertise in blue-green and grey infrastructure from a range of disciplinary backgrounds: for example, engineering, environmental management, implementation, landscape architecture and design, planning, and policy. The sample population is drawn from professionals engaging with the research project '*Developing new Blue-Green futures: multifunctional infrastructure to address water challenges*', part of the British Academy programme on Tackling the UK's International Challenges (Blue-Green Futures 2019). This project explores how four international cities, at the forefront of BGI implementation in their respective countries (Newcastle, UK; Rotterdam, The Netherlands; Portland, Oregon, USA; and Ningbo, China), are tackling urban flood and water challenges and developing visions for *Blue-Green urban futures*, characterised by widespread implementation of multifunctional BGI that delivers multiple benefits for the environment, society, and economy (O'Donnell *et al.* 2021). For instance, Rotterdam is an international leader in aligning climate change adaptation, water management, and spatial planning to increase urban resilience to the impacts of climate change, while concurrently improving quality of life (Tillie & van der Heijden 2016). Ningbo is a Chinese pilot city in the 'Sponge City Programme', tasked with integrating low-impact development and BGI with urban planning to mitigate flood risk, manage stormwater, improve water quality, and store water for future use (Jiang *et al.* 2017). Portland has invested widely in BGI over the last two decades to alleviate loadings on the piped infrastructure system, improve water quality, and manage flood risk (McPhillips & Matsler 2018), and has one of the oldest and most successful GI programmes in the United States. Finally, risk management authorities in Newcastle are investing in combinations of blue-green and grey infrastructure to improve the city's resilience to future flooding while delivering social and environmental benefits from above-ground, attractive BGI systems (Amec Foster Wheeler 2016).

This geographically targeted investigation used purposive sampling (Tongco 2007) to select participants in the four cities and provide a breadth of experiences around blue-green and grey infrastructure. As a random sample of professional stakeholders was not taken, the findings are specific to the sample group. Limited sample sizes in each city preclude a comparison of perceptions in Newcastle, Ningbo, Portland, and Rotterdam (O'Donnell *et al.* 2021). Location is one of the many factors that could influence perceptions of BGI, as could awareness of purpose and function

[1] A visual scale that enables respondents to express their attitudes about a given subject by applying a numeric rating of their feelings (referred to as 'slider bars' in the USA).

(Everett *et al.* 2018), broader environmental attitudes around climate change (Schultz *et al.* 2004), demographic factors, and how facilities are used within the public realm (Lamond & Everett 2019). As these factors were not controlled, we rationalise that our data present general insight into perceptions of blue-green and grey infrastructure in the four cities, and recommend further investigation to uncover the influence that the aforementioned factors, including location, have on perceptions of BGI. We expect respondents to express positive explicit perceptions of BGI, owing to the expert knowledge they hold of the benefits of such approaches and their professional role in BGI strategy, planning, design, and implementation. To our knowledge, this is the first comparative study of the implicit and explicit perceptions that professional stakeholders have of blue-green and grey infrastructure, and, hence, presents a novel exploration of whether stated preferences for BGI align with unconscious perceptions. This research also contributes to the urban studies literature by providing the first insight into implicit perceptions of blue-green and grey infrastructure which play a key, but previously unexplored, role in influencing attitudes and behaviours around urban water management.

Methods

Online surveys

The sampling frame was professional stakeholders with expertise in BGI, stormwater management and/or climate change adaptation and mitigation, urban planning, design, and implementation. Participants were drawn from government organisations, private organisations (such as UK water companies or environmental consultancies), academia, and nonprofits (such as environmental charities and advocacy groups). Participants were recruited with a personalised email from the research team, and directed to the online survey. Forty-four participants were invited with 93 per cent (n = 41) completing all questions (fourteen from Newcastle, and nine each from Ningbo, Rotterdam, and Portland). The survey took approximately 10 minutes to complete and was open from July 2019 until January 2020. Four identical surveys were launched: one using UK English, one US English, one in Dutch, and one in Chinese. As the IAT score was determined by response times to different pairings of target-concepts and evaluative attributes, it was imperative that respondents understood the instructions and that the words used were easy to visualise and unambiguously classifiable: hence, the need for four tests.

Participants read a participant information sheet and granted consent prior to completing the survey. Participants were first asked to read a definition of BGI to remove any ambiguities regarding the meaning of BGI in this study: '*Blue-green infrastructure (including swales, rain gardens, green roofs, wetlands, street trees, and ponds) is an approach to stormwater and flood risk management that uses vegetation and soils to enhance and/or mimic the natural hydrological cycle processes of infiltration, evapotranspiration and reuse.*' They then completed the BGI feeling thermometers. Participants were next asked to read a definition of grey infrastructure: '*Traditional grey infrastructure refers to the human-engineered infrastructure used in conventional piped drainage, storage, water treatment and water supply systems. Infrastructure includes storm drains, storage tanks, culverts, subsurface pipes and combined sewer overflows. It typically refers to components of a centralised approach to water management.*' They then completed the grey infrastructure feeling thermometers. Words were used instead of photographs in all tests in order to assess participants' internal understanding of blue-green and grey infrastructure and avoid introducing bias associated with image choice. Finally, participants completed the IAT (detailed subsequently).

Explicit test: feeling thermometer

Participants completed twelve thermometers to assess their feelings towards the safety, attractiveness, tidiness (or, for the US tests, how maintained they are perceived to be, which is more commonly used to describe the appearance of BGI), usefulness, valuableness, and necessity of blue-green and grey infrastructure (Appendix 1). Participants were instructed to click anywhere on the feeling thermometer to activate the slider and then drag the slider to the point that best reflects their feelings for each attribute. Scales ranged from 0 (for example, extremely unsafe) to 100 (extremely safe). As the initial starting position of the slider can influence the score—for example, respondents are more likely to select the slider's default value (Liu & Conrad 2019)—the thermometers were designed without a default value. Clear instructions were given regarding how responses may be registered to reduce the risk of non-response (Roster *et al.* 2015). Averages of the six scores for BGI, and six scores for grey infrastructure, were calculated. Thermometer Difference (TD) scores were then calculated by subtracting the average BGI score from the average grey infrastructure score, and then normalised to a −2 to +2 scale to be consistent with the IAT D-score. Positive TD-scores indicate a preference for BGI, while negative scores reflect a preference for grey infrastructure.

Implicit Association Test (IAT)

The IAT method described by Greenwald *et al.* (1998) was followed and adapted to compare the automatic associations of blue-green and grey infrastructure. The appearance, instruction text, and programming of the new online IATs were based on the FreeIAT software (Meade 2009). Two types of stimuli were used: target-concepts and evaluative attributes. Target-concepts comprised seven words describing common types of BGI, and seven words describing grey infrastructure that are frequently used to manage stormwater (as shown in Table 1). The evaluative attributes consisted of seven positive and seven negative words that were originally selected from an online thesaurus as frequently used English-language synonyms for positive and negative concepts, and align with the attributes tested in the feeling thermometers. Of primary importance was that the words were easy to visualise and unambiguously classifiable as positive or negative; the actual selection of the words were of secondary importance as IAT scores typically reflect attitudes towards the overarching target-concepts rather than attitudes towards the individual exemplars of those concepts (De Houwer 2001). The implicit perceptions of safety, attractiveness, tidiness, usefulness, valuableness, and necessity (the six attributes tested in the feeling thermometers) are not directly assessed by the IAT but influence the resulting score.

Each IAT began with an introduction to the test and instructions for the participants (Appendix 2). The IAT consists of five blocks, each block containing twenty trials whereby each trial is associated with one stimulus, either a target-concept or evaluative attribute word (as shown in Table 2). Stimuli are randomly selected in all tests and then entered back into the selection processes: that is, a word could appear multiple times during one trial block. During the test, the randomly selected stimuli are presented, one at a time, in the centre of the screen and participants are asked to categorise each stimulus as quickly as possible using the left ('e') and right ('i') keys. The categories that the 'e' and 'i' keys represent are listed at the top of the screen, and are different in each block depending on the task description (for example, initial combined task), as illustrated in Table 2, with the solid black circles indicating allocation of the stimulus to either the left ('e') or right ('i') hand responses. For example, in Block 1 (initial target-concept discrimination), the participant would select the 'e' key if the stimulus was a word describing BGI, or the 'i' key if the word described grey infrastructure. Each stimulus is shown on the screen until a correct response (that is, the classification of the stimulus into the pre-selected categories), is registered. If an

Table 1. Words used in the Implicit Association Test (IAT); positive and negative evaluative attribute words, and target-concepts describing Blue-Green Infrastructure (BGI) and Grey infrastructure.

Positive words	Attractive, Clean, Healthy, Reliable, Safe, Useful, Valuable
Negative words	Dangerous, Dirty, Ugly, Unhealthy, Unreliable, Useless, Worthless
Blue-green infrastructure	Green roof, Green wall, Retention pond, Rain garden, Street tree, Swale, Wetland
Grey infrastructure	Combined sewer overflow, Culvert, Sewer, Storm drain, Subsurface pipe, Underground storage tank, Storm sewer

Table 2. Trial blocks in the Implicit Association Test (IAT). A solid black circle indicates allocation of a word to a left ('e') or right ('i') hand response. Modified after Greenwald *et al.* (1998).

Block	1	2	3	4	5
Task description	Initial target-concept discrimination	Evaluative attributes discrimination	Initial combined task	Reversed target-concept discrimination	Reversed combined task
Number of trials	20	20	20	20	20
Task instructions	● Blue-green	● Positive	● Blue-green ● Positive	● Blue-green	Blue-green ● Positive ●
	Grey ●	Negative ●	Grey ● Negative ●	● Grey	● Grey ● Negative
Function	Practice	Practice	Test	Practice	Test

incorrect response is given (for example, by classifying a retention pond as grey infrastructure), a red 'X' appears on the screen and the respondent must select the correct response key for the test to continue.

If participants find one of the combined tasks (blocks 3 or 5) easier (or faster to respond to) than the other, this means that they differentially associate target-concepts with evaluative attributes, which provides a measure of the implicit attitudinal difference among the target-concept categories. The IAT effect (called the 'difference' or D-score) is the difference between the average response time across all trials in block 5 minus the average response time in block 3. D-scores were calculated using the improved scoring algorithm (Greenwald *et al.* 2003) adapted for five blocks rather than the original seven (O'Donnell *et al.* 2020a). D-scores range from −2 to +2. Following standard practice, trials with response times >10000 ms or <300 ms for more than 10 per cent of their trials, were removed (Greenwald *et al.* 2003). The block mean of correct trials + 600 ms was added to trials initially answered incorrectly. A high D-score indicates that BGI was more closely associated with positive concepts and/or less closely associated with negative concepts, than grey infrastructure. D-scores between −0.2 and +0.2 are considered neutral, indicating no preference (Beattie & McGuire 2012).

Results

The mean explicit TD-score was 0.66 (SD = 0.52, n = 41), indicating that the sample population has an explicit preference for BGI (Figure 1; all scores are provided in Appendix 3). TD-scores ranged from −0.36 to 1.55. 78 per cent of the individual respondents expressed an explicit preference for BGI compared with 15 per cent who

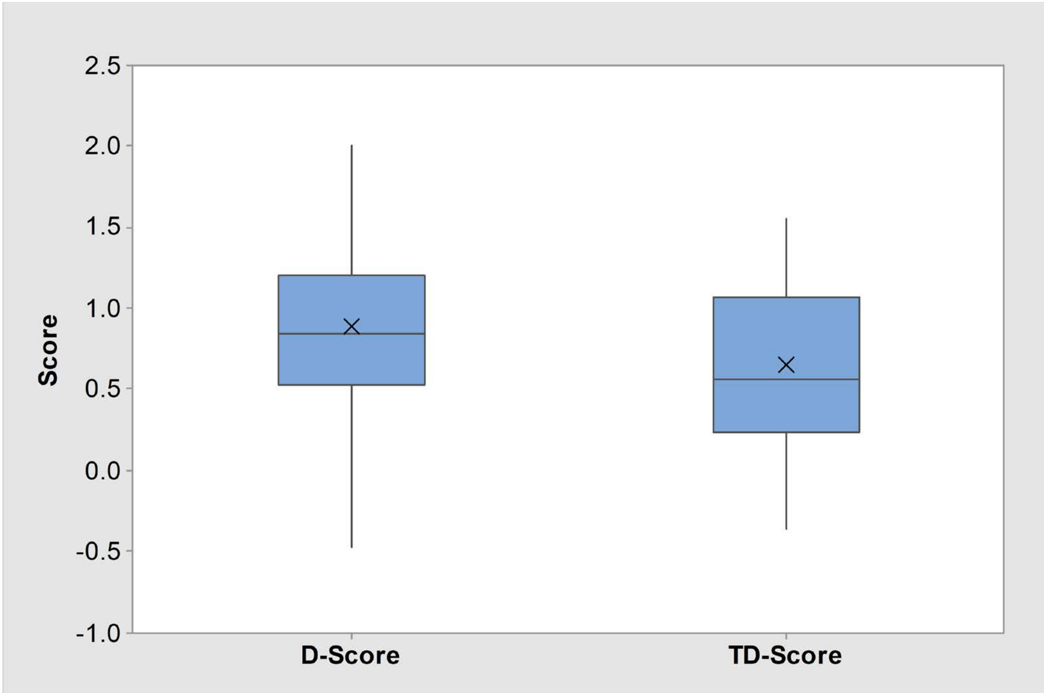

Figure 1. Distributions of D-scores (IAT) and normalised TD-scores (feeling thermometer). The median score is denoted by the centre line, the mean is the cross, the box denotes the Interquartile Range (IQR), and the upper (and lower) whiskers extend to the maximum (and minimum) data point within 1.5 times the IQR.

gave a neutral response and 7 per cent who demonstrated a preference for grey infrastructure (Figure 2). The mean implicit D-score was 0.89 (SD = 0.52, $n = 41$), indicating a slightly stronger implicit preference for BGI within the sample population (Appendix 4). D-scores ranged from −0.47 to 2.00. 90 per cent of individual responses showed an implicit preference for BGI, compared with 7 per cent who exhibited a neutral response and 2 per cent who showed an implicit preference for grey infrastructure (Figure 2). TD-scores and D-scores exhibited normal distributions (Shapiro–Wilk test, $p = 0.299$ and $p = 0.624$, respectively). Statistical analyses were conducted with SPSS 25.0.

A weak but statistically significant correlation was observed between TD-scores and D-scores ($r = 0.380$, $p = 0.014$), which is comparable to correlations reported between explicit tests and IATs in earlier research (Hofmann *et al.* 2005, Rudman *et al.* 2013, O'Donnell *et al.* 2020a). This further demonstrates the importance of IATs in research into such environmental attitudes (Schultz *et al.* 2004). Despite this, TD-scores and D-scores were significantly different ($t = 1.995$, $p = 0.049$, Independent Samples T-test). Higher variability in TD-scores is demonstrated by the greater

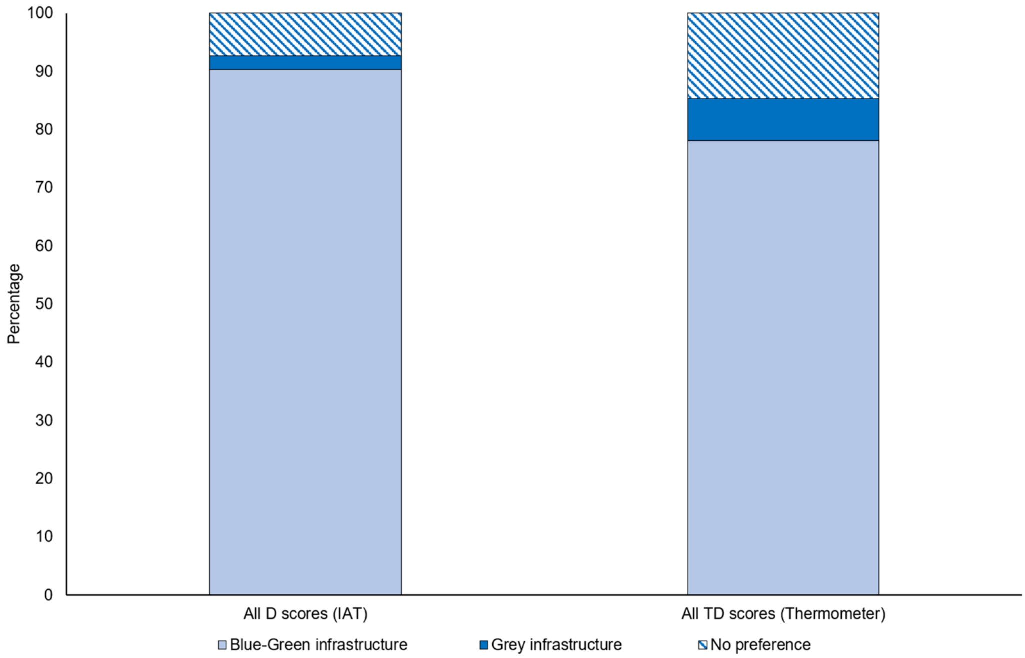

Figure 2. The percentages of respondents who demonstrated a preference for Blue-Green Infrastructure, Grey infrastructure, or no preference, for all data (n = 41), based on the Implicit Association Test (IAT) D-scores and Feeling Thermometer Difference (TD) scores.

interquartile range (IQR; Figure 1) compared with D-scores that clustered more around the mean with some longer whiskers (upper and lower) suggesting several strongly positive and negative individual implicit perceptions.

Explicit characteristics of blue-green and grey infrastructure

The positive average scores in the six feeling thermometer subcategories, excluding attractiveness of grey infrastructure, show that respondents have positive feelings towards blue-green and grey infrastructure (as shown in Table 3 and Figure 3) and regard both types of infrastructure as safe, tidy, useful, valuable, and necessary. However, only BGI was regarded as attractive. Overall, BGI is regarded, in a statistical sense, as significantly safer, more attractive, more useful, more valuable, and of greater necessity than grey infrastructure (Table 3, Independent Samples Mann–Whitney U-tests). BGI is perceived, on average, as tidier than grey infrastructure, although this relationship is not statistically significant.

Despite these overarching trends, the data reveal much variability in perceptions of blue-green and grey infrastructure. Attributes of BGI assessed by the feeling thermometers show greater agreement within the sample population (smaller standard

Table 3. Median scores in the six feeling thermometer subcategories. All scores are normalised to a −2 to 2 scale, standard deviation is given in parentheses and the range in italics. The larger the score, the greater preference for the target variable.

	Safety	Attractiveness	Tidiness[b]	Usefulness	Valuableness	Necessity
Blue-Green	1.60 (0.66)	1.56 (0.60)	0.80 (0.74)	1.80 (0.54)	1.72 (0.49)	1.84 (0.61)
	−0.80 to 2.00	*−0.56 to 2.00*	*−1.70 to 2.00*	*−0.04 to 2.00*	*−0.20 to 2.00*	*−0.16 to 2.00*
Grey	1.16 (0.94)	–0.96 (0.81)	0.68 (0.97)	1.20 (0.78)	1.12 (0.69)	1.20 (0.81)
	−2.00 to 2.00	*−2.00 to 0.72*	*−1.60 to 2.00*	*−1.04 to 2.00*	*−0.80 to 2.00*	*−1.28 to 2.00*
***p*-value**[a]	0.008	0.000	0.133	0.003	0.000	0.016

[a] Significant difference between Blue-Green and Grey scores under each category were assessed using Independent-Samples Mann–Whitney U-tests; significant differences at the $p = 0.05$ level are underlined. Data in all subcategories, excluding 'Tidiness—Blue-Green' and 'Valuable—Grey exhibited non-normal distributions (Shapiro–Wilk test, $p \leq 0.05$).
[b] Tidiness or maintained (US test).

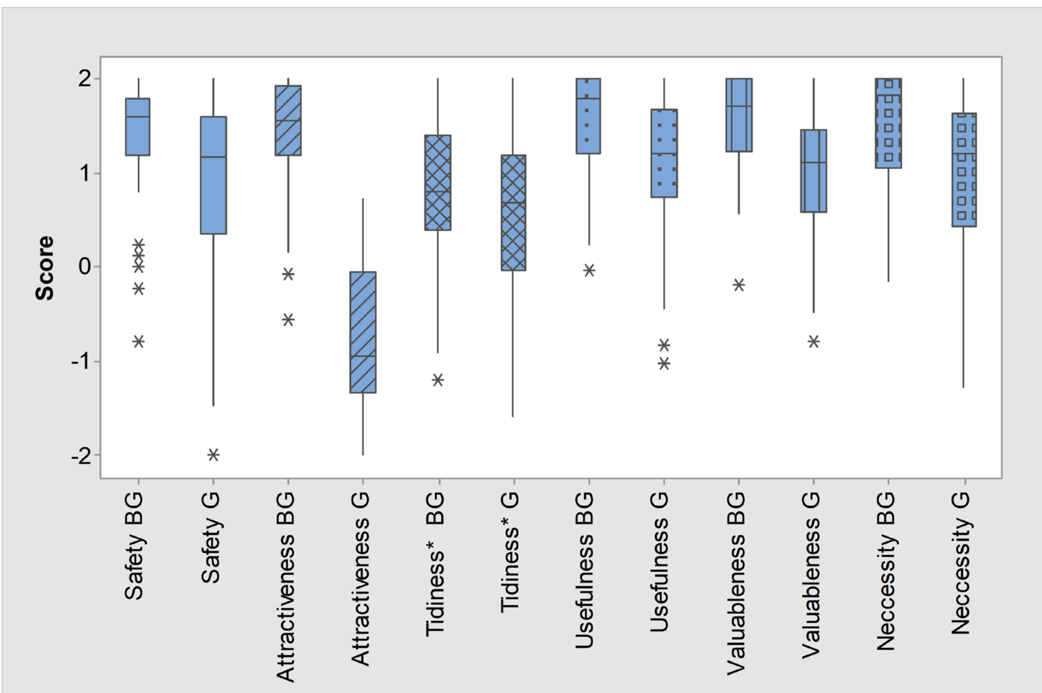

Figure 3. Distributions of feeling thermometer scores for Blue-Green (BG) and Grey (G) infrastructure in the six categories. The median score is denoted by the centre line, the box denotes the Interquartile Range (IQR), and the upper (and lower) whiskers extend to the maximum (and minimum) data point within 1.5 times the IQR. Outliers (starred) are data points beyond the lower whiskers. *tidiness or maintained (US test).

deviations and IQRs) when compared with grey infrastructure where views are more variable (Figure 3). The longer negative whiskers for the grey infrastructure attributes suggest that several respondents feel strongly that grey infrastructure is unsafe, unattractive, untidy, useless, not valuable, and unnecessary. Aside from the unattractiveness of grey infrastructure that is supported by the majority (76 per cent) of respondents, negative perceptions of the other attributes of grey infrastructure typically represent a minority of strong negative preferences within the general population that regard grey infrastructure more favourably, including three respondents with outlier scores (two from Ningbo, one from Portland). With regards to BGI, several respondents hold negative perceptions of BGI attributes, as represented by the negative outliers in Figure 3 for BGI safety (5), attractiveness (2), tidiness (1), usefulness (1), and valuableness (1). The outliers for BGI attributes represent six respondents, all from Ningbo.

Significant positive correlations were observed between several BGI attributes, including attractiveness and tidiness ($r = 0.429$, $p = 0.006$) and safety and usefulness ($r = 0.460$, $p = 0.002$) (Spearman's rank-order correlations, detailed in Appendix 5). The strongest correlations were observed between usefulness and necessity ($r = 0.657$, $p = 0.000$), usefulness and valuableness ($r = 0.610$, $p = 0.000$), and valuableness and necessity ($r = 0.816$, $p = 0.000$). Similarly, the usefulness and valuableness of grey infrastructure were positively correlated ($r = 0.603$, $p = 0.000$), as were usefulness and necessity ($r = 0.456$, $p = 0.003$), valuableness and necessity ($r = 0.495$, $p = 0.001$), and safety and usefulness ($r = 0.567$, $p = 0.000$).

Discussion

Using IATs to assess perceptions of blue-green and grey infrastructure held by professional stakeholders working closely with these infrastructures is a notable advance from tests solely employing explicit measures (Miller & Montalto 2019, Shandas *et al.* 2019, Suppakittpaisarn *et al.* 2019). The data presented in this paper contribute to our growing understanding of the complexity of attitudes towards blue-green and grey infrastructure, and attributes that influence preferences (for example, safety, attractiveness, and necessity), by presenting insight into unconscious perceptions and subsequently comparing those with stated preferences.

Explicit and implicit preferences for blue-green and grey infrastructure

The majority of respondents in the sample population associate BGI more closely with positive concepts (and/or less closely with negative concepts) than grey infrastructure, suggesting an agreement between conscious and subconscious attitudes that BGI is more highly valued than grey infrastructure. Several reasons may provide an explanation. The sample population is expected to be highly knowledgeable about the advantages, disadvantages, benefits, challenges, opportunities, and uncertainties associated with blue-green and grey infrastructure, owing to their current roles and disciplinary expertise in blue-green and grey infrastructure policy, planning, design, engineering, and implementation. Participants may acknowledge the greater multi-functionality of BGI: that is, that BGI delivers a wider range of social, environmental, and economic benefits compared with grey infrastructure (Hansen & Pauleit 2014, Fenner 2017, Alves *et al.* 2019a, Paulin *et al.* 2020). Recognition of the multiple benefits of BGI beyond water treatment and flood control have also been highlighted in focus groups with thirteen professional stakeholders in Portland and Clark County, Washington (Shandas *et al.* 2019), and online surveys with twenty New York City practitioners that showed that groups most familiar with BGI (such as practitioners) typically assign the most value to the ecosystem services that BGI provides (Miller & Montalto 2019).

Respondents may assume that BGI is a more effective use of space and, if designed with multifunctionality in mind, can address local challenges, including flooding, air pollution, urban heat island effects, and biodiversity loss (Connop *et al.* 2016). While the definitions of BGI and grey infrastructure given at the start of the explicit tests referred to their respective roles in flood and water management, additional benefits (for example, environmental enhancement, climate change adaptation, or improvements to health and well-being) were not mentioned to avoid potential response bias. The feeling thermometer instructions asked respondents to state, for example, how useful they feel BGI is; the context of 'usefulness' was not dictated, hence, the meaning was interpreted by the respondents before they gave their score.

BGI could also be perceived as a proxy for nature and greater preference for BGI could imply a higher connectedness with nature, compared with built environments, as observed by Schultz *et al.* (2004). Similarly, it could be that respondents prefer natural over built environments (Kaplan & Kaplan 1989) and the terms 'Blue-Green infrastructure' and 'Grey infrastructure' conjured subconscious and/or conscious images of blue-green and grey systems at much larger spatial scales. Nonetheless, it is beyond the ability of the IAT to explain *why* implicit perceptions are more closely associated with positive concepts than grey infrastructure. Due to the relative nature of the IAT, it is also impossible to discern whether respondents have a positive association with BGI or a negative association with grey infrastructure (or both), which is an important limitation (Siegrist *et al.* 2006). Explanation of attitudes towards blue-green and grey infrastructure are likely to be more nuanced and context specific, which preclude capture by the IAT or feeling thermometers. As one respondent from Portland noted:

> *Grey is not good or bad but needed where it is needed. The difference is a designer's ability to know when and how much grey is needed with green and vice versa.*

Two lines of evidence suggest a slightly stronger implicit (compared with explicit) preference for BGI within the sample population: a higher mean D-score (0.89) compared with the mean TD-score (0.66), and a greater percentage of individual respondents registering a positive score (above neutral) in the IAT compared with the explicit test (90 per cent implicit, 78 per cent explicit, Figure 2). This may be because some of the explicit concerns that respondents have towards BGI are not held in the subconsciousness; respondents are thus expressing more negative feelings than they instinctively feel. Alternatively (or in addition), respondents may rationalise about the advantages and disadvantages of grey infrastructure and decide to highlight positive attributes in the explicit tests; such positive associations may not be part of the internalised concept of grey infrastructure that respondents hold, leading to a stronger implicit (compared with explicit) preference for BGI.

These findings also suggest that social desirability bias, which would have increased the positive explicit scores given to BGI as part of an embedded response of 'liking' all greenspace, was not an important issue. Additionally, the design of the explicit tests, and particularly the attributes used in the feeling thermometers, allowed respondents to rationalise the advantages and disadvantages of grey infrastructure (for example, valuableness vs. attractiveness), which may have resulted in more negative and neutral views overall. Respondents may also have rationalised about the limitations of BGI, including the limited functionality when its design capacity is exceeded, which may be perceived as likely during extreme rainfall events now and in the future (Kabisch *et al.* 2016). This may have influenced the perceptions of usefulness and necessity of BGI approaches. The automatic or spontaneous nature of implicit attitudes, not available through introspection but revealed through the computerised reaction time IAT (Beattie and McGuire 2012), negates such deliberative behaviour (Nosek *et al.* 2002, Hofmann *et al.* 2005).

Variability in responses was evident, suggesting that some professional stakeholders within the sample population do have stronger implicit and explicit attitudes towards blue-green and/or grey infrastructure (D-scores ranged from −0.47 to 2.00 and TD-scores ranged from −0.36 to 1.55). This is further illustrated by the wide range of scores for the individual feeling thermometers measuring the six selected attributes of blue-green and grey infrastructure (as shown in Table 3 and Figure 3), and will be explored in the next section.

Perceptions of attractiveness, tidiness, safety usefulness, valuableness, and necessity

Overall, there was consistency in the positive explicit perceptions of the safeness, tidiness, usefulness, valuableness, and necessity of blue-green and grey infrastructure. Unsurprisingly, respondents found BGI significantly more attractive than grey infrastructure, although 15 per cent of respondents scored grey infrastructure positively, suggesting some appreciation of the aesthetics of this approach. Aside from attractiveness, the negative scores for safety, tidiness, usefulness, valuableness, and necessity of grey infrastructure typically represent a minority of strong negative preferences within the general sample population that regard grey infrastructure more favourably. Outlier scores from three respondents demonstrate strong individual feelings that grey infrastructure is highly unsafe, useless, and not valuable. Similarly, several respondents also hold negative perceptions of BGI safety, attractiveness, tidiness, and valuableness, yet this is a small, outlying minority and should not unduly influence decision making around blue-green and grey infrastructure. However, the fact that the negative outliers for BGI attributes were recorded by six (out of a total of nine) respondents from Ningbo suggest that contextual factors may be influencing explicit perceptions. As five out of the ten negative outliers for BGI attributes refer to safety, there appears to be concerns within Ningbo respondents that BGI is not safe. This requires further investigation as, to our knowledge, there are no further investigations of professional Chinese stakeholder perceptions of the safety of BGI. Concerns around the safety of green roofs were raised by public respondents in Shandong province, China (Wang *et al.* 2017), but we cannot infer whether this reflects the views of Chinese stakeholders in general, or the specific Shandong public sample population.

The lower scores for BGI tidiness reflect the ongoing debate regarding a preference for 'messy' or 'tidy' nature; certain plant species used in BGI (for example, *Juncus* rushes) may be mistaken by some stakeholders for overgrown grasses and weeds and perceived as less aesthetically pleasing (Everett *et al.* 2018), whereas other stakeholders may regard 'messy' BGI as more aligned with natural environments (Tyrväinen *et al.* 2003) and, hence, desirable in urban contexts. The significant positive correlation between scores for attractiveness and tidiness suggests that 'tidy BGI' would be regarded as even more attractive within the sample population. This correlation was also observed in an earlier analysis of resident's perceptions of SuDS (O'Donnell *et al.* 2020a), showing agreement between explicit perceptions of residents and professional stakeholders regarding BGI aesthetics.

The lower scores for the safety of grey infrastructure may be due to some respondents perceiving greater consequences of grey infrastructure failure, which, historically, has seldom been designed to be 'safe-to-fail' (Dong *et al.* 2017) and can potentially induce catastrophic impacts (for example, floodwall collapse)

(Debele *et al.* 2019). Grey infrastructure, like BGI, is designed for a range of different events: for example, urban highway drainage systems in China are designed to manage pluvial flood risk for 1:1 to 1:10 year events (Ministry of Housing and Urban–Rural Development 2016). However, unlike BGI, grey infrastructure is also used to manage coastal and fluvial flood risk associated with high magnitude events: for example, the Rotterdam dyke rings are designed for between 1:4,000 and 1:10,000 year events (City of Rotterdam 2013).While the definition of grey infrastructure that was provided at the start of the explicit test referred to '*the human-engineered infrastructure used in conventional piped drainage, storage, water treatment and water supply systems*', and gave examples of '*storm drains, storage tanks, culverts, subsurface pipes and combined sewer overflows*', it is possible that respondents had an entrenched concept of grey infrastructure that included larger scale assets, which subsequently influenced their responses. The design standards of BGI systems vary by scheme and by city: for example, most urban BGI in the Chinese Sponge Cities are designed to drain runoff from up to 1:30 year rainfall events (Chan *et al.* 2018), whereas the design standard for most UK SuDS is 1:30 years as a minimum (Woods Ballard *et al.* 2015). Consequentially, the risks associated with rainfall events exceeding the design standards of BGI are lower; if exceedance pathways are included, then BGI can be designed to provide some flood reduction benefit when its design capacity is exceeded (Digman *et al.* 2014).

Most respondents regard BGI as significantly safer, more useful, more valuable, and of greater necessity than grey infrastructure, which suggests a widespread acknowledgement of the functionality (or multifunctionality) of BGI and benefits beyond aesthetics. BGI could be perceived as more useful and valuable due to concurrent delivery of multiple environmental and social benefits in addition to the intended benefit to, typically, flood and water management, as discussed in the preceding paragraph. BGI may be perceived as of greater necessity when compared with grey infrastructure due to its ability to reduce vulnerability to other climate change risks beyond flooding, such as heat stress, water shortages, and air pollution (Demuzere *et al.* 2014). Both Rotterdam and Portland have developed strategies to address climate change—for example, the Rotterdam Climate Change Adaptation Strategy (City of Rotterdam 2013) and Portland's Climate Action Plan (City of Portland and Multnomah County 2016)—and, hence, the necessity of BGI to address multiple components of these strategies may have been in the consciousness of the respondents. Likewise, Policy CS16 (Climate Change) in the *Core Strategy and Urban Core Plan for Gateshead and Newcastle upon Tyne 2010–2030* (UK) refers to development providing resilience to the ongoing and predicted impacts of climate change through appropriate location, design, and landscaping (Newcastle City Council and Gateshead Council 2015). Existing grey pipe systems designed to manage urban water have reduced the ability to modify system performance in light of future, uncertain, changes in climate and may also lead to technical lock-in (Ashley *et al.* 2020, Kapetas & Fenner 2020), which may further reduce the perception of usefulness, valuableness, and necessity. In contrast, BGI is acknowledged for its greater adaptability and higher system sustainability under uncertain futures (Dong *et al.* 2017).

The significant positive correlations between usefulness, valuableness, and necessity of BGI and grey infrastructure could imply a similar interpretation of the meaning of the three attributes, and, hence, using all three may be redundant in future studies. In this investigation, TD-scores were calculated by subtracting the average BGI score from the average grey infrastructure score, using an average of the scores for the six attributes. Excluding valuableness and usefulness, and calculating the average BGI and grey scores based on values given for safety, attractiveness, tidiness, and necessity only, did not affect the TD-score (Appendix 6). Interestingly, if attractiveness scores are removed from the TD-score calculation, the TD-score is reduced by 50 per cent (from 0.66 to 0.33, Appendix 6). This implies that attractiveness is a key influential factor in positive perceptions of BGI, and, if attractiveness was not assessed, the preference for blue-green compared with grey infrastructure would be weaker and approaching neutral (0.2).

Integrated systems of blue-green-grey infrastructure

Although most respondents in the sample population associate BGI more closely with positive concepts (and/or less closely with negative concepts) than grey infrastructure, the majority of individual positive explicit perceptions of the safeness, tidiness, usefulness, valuableness, and necessity of blue-green and grey infrastructure suggest that both infrastructure types are valued by the sample population, albeit, with regards to grey infrastructure, on an explicit level only. From this we can infer that integrated systems of blue-green and grey infrastructure may be a preferable strategy in managing urban water and mitigating the impacts of climate change, in addition to delivering benefits to the environment, society, and economy. There is a growing body of evidence that resilience against future environmental threats cannot be achieved by traditional grey infrastructure systems alone, and combinations of blue-green and grey infrastructure can enhance system performance and maximise climate adaptation in cities (Dong *et al.* 2017, Alves *et al.* 2019b, Browder *et al.* 2019, Debele *et al.* 2019, Frantzeskaki *et al.* 2019, O'Donnell *et al.* 2020b, Kapetas & Fenner 2020). The use of traditional buried pipe networks to address, for example, future water challenges associated with climate change and increased urbanisation, is likely to be unaffordable, miss wider opportunities that integrated blue-green and grey approaches could deliver (Dolman & Ogunyoye 2018, Ashley *et al.* 2020), and potentially lead to overdesigned solutions or inadequate system extensions that fail to provide the required additional capacity (O'Donnell & Thorne 2020). BGI and Nature-Based Solutions (NBS) are typically more cost effective than hard engineering approaches used within existing systems, particularly when wider co-benefits are quantified and, where possible, monetised (Braden & Ando 2011, Ando & Netusil 2018, Debele *et al.* 2019).

Taking the projected increase in frequency and intensity of rainfall events as an example (IPCC 2014), the potential integration of blue-green and grey infrastructure to manage urban rainfall can be viewed through four domains, with different combinations of blue-green–grey assets needed to deliver maximum benefit in urban areas: 1) urban resource (everyday rainfall); 2) urban drainage (design rainfall); 3) exceedance design (exceedance rainfall); and 4) flooding domain (extreme rainfall) (Fratini *et al.* 2012, Ashley *et al.* 2020). Combined systems of blue-green–grey infrastructure can manage pluvial flood risk in all domains. In Domain 1, BGI should play a key role in managing smaller rainfall events, which are within the design standard of most assets, and is typically included at an urban planning stage to manage low levels of risk while contributing to quality of place. At the other end of the scale (Domain 4), the impacts of extreme rainfall events can be minimised through effective emergency response measures (including evacuation) and provision of floodable areas. This could include BGI assets such as playing fields, parks ,and open greenspace, in addition to grey infrastructure assets specifically designed to reduce pluvial flood risk, such as the Benthemplein water square in Rotterdam, which manages rainwater while redeveloping the urban environment (Hölscher *et al.* 2019), or designated as floodable, such as car parks. The optimum mix is highly dependent on local conditions (Dong *et al.* 2017, Kapetas & Fenner 2020).

An integrated blue-green–grey approach increases the complexity of options and delivery, moving from a mono-solution problem when grey infrastructure is the sole consideration (Ashley *et al.* 2020) to a multifaced challenge involving a range of public and private stakeholders from different disciplinary standpoints, and consideration of multiple co-benefits beyond water and flood risk management. Nonetheless, integrated blue-green–grey approaches are recommended to help cities progress towards the Sustainable Development Goals (SDGs), particularly around good health and well-being (SDG3), clean water and sanitation (SDG6), and sustainable cities and communities (SDG11). An adaptation pathways approach can reduce this complexity and allow incremental investment in infrastructure to meet future performance requirements while maintaining cost-effectiveness and multiple benefit provision (Kapetas & Fenner 2020). Using a residential case study in a London Borough, Kapetas and Fenner (2020) show that combining BGI interventions (storage pond, bioretention cells, and permeable paving) with the existing grey infrastructure system can more effectively manage future flood risk and maximise other co-benefits (for example, amenity, carbon sequestration, and groundwater recharge opportunities), when compared with grey infrastructure expansion alone. Determining the importance of each benefit at the start of spatial development strategy planning is recommended; not all benefits can be optimised simultaneously and trade-offs will need to be made regarding which risks are to be minimised (Caparros-Midwood *et al.* 2019). For instance, if a blue-green–grey strategy driven by flood risk management objectives achieves the highest total benefit, but compromises flood damage reduction, such a trade-off may not be acceptable to the stakeholders involved (Alves *et al.* 2019b). Smart Specialisation Strategy, to achieve the objectives of cohesion policy, may be drawn upon to enable regional authorities to identify technological domains to concentrate investment and innovation (D'Adda *et al.* 2020), in this case focusing on innovative systems of integrated blue-green–grey infrastructure.

Limitations and directions for future research

The IAT is widely used to reveal implicit attitudes through the strength of concept–attribute associations. Limitations of this method, including the inability to discern whether respondents have a positive association with one target-concept and/or a negative association with the other, were discussed in earlier literature (e.g., Greenwald *et al.* 1998, Rudman *et al.* 1999, Siegrist *et al.* 2006, Gregg & Klymowsky 2013). The logistical challenges, namely the need for a computer to complete the test, are less relevant in current society, and particularly in the professional stakeholder sampling frame used in this study. Still, variations in internet speeds, computer specifications, and distractions may have affected the response times when respondents completed the online IAT, influencing the resultant implicit score. The software is designed to minimise this potential issue: for example, by training respondents first in the two trial runs before the initial combined task (Table 2) and by eliminating responses that exceeded 10,000 ms. Nonetheless, it is accepted that the degree of variability and noise may be larger with implicit attitude measures, when compared with explicit measures (Schultz *et al.* 2004).

Designing the feeling thermometers without a default value is expected to have limited any bias associated with the slider starting position (Liu & Conrad 2019), and thus recorded a representative indication of how the respondents feel towards the six attributes tested. The explicit test score (Thermometer Difference or TD-score), however, is dependent on the attributes used in the feeling thermometers, and it is possible that using different words would have resulted in different scores. This could have resulted in greater explicit preference for BGI (compared with implicit), or even an explicit preference for grey infrastructure. TD-scores calculated using values given for safety, attractiveness, tidiness, and necessity (so excluding valuableness and usefulness) did not affect the TD-score, but removing attractiveness from the TD-score calculation reduced the TD-score by 50 per cent (Appendix 6). The selection of attributes in the explicit tests, and the degree to which the explicit measure is directly or indirectly related to the representation assessed in the IAT, are of paramount importance and influence the degree to which explicit and implicit scores can be compared (Hofmann *et al.* 2005).

The IATs and feeling thermometer tests are unable to explain why certain attitudes and preferences are held within the sample population. Future research could build on this study by explicitly asking respondents why they perceive (or do not perceive) blue-green and grey infrastructure as attractive, safe, tidy or well-maintained, useful, valuable, and necessary, and exploring their feelings towards integrated systems of blue-green–grey infrastructure to address climate change adaptation objectives. Further research could explore more applied questions: for example, investigating whether experience of flood events influences implicit perceptions of blue-green and grey infrastructure, as direct experience with extreme weather events is acknowledged as an effective catalyst for changing implicit attitudes (Rudman *et al.* 2013). Collecting data from a larger sample population in each of the four cities, which would have permitted a comparison of perceptions in Newcastle, Ningbo, Portland, and Rotterdam, and an investigation into whether location and associated governance characteristics could influence implicit perceptions of BGI, may not be possible due to the limited population (in each city) of professional stakeholders working with BGI. However, this should be investigated in future research. Additionally, evaluating whether broader environmental attitudes around climate change influence perceptions of blue-green and grey infrastructure could also develop insight into why certain perceptions are held.

Conclusion

Blue-Green Infrastructure (BGI) is increasingly acknowledged as a strategy to reduce the impacts of climate change in urban environments and reduce vulnerability to risks such as flooding, heat stress, and water shortages, while delivering a range of additional co-benefits to the environment and society. Through the development of a novel application of the Implicit Association Test (IAT), this study investigated the perceptions of BGI held by professional stakeholders in four cities with leading BGI programmes and aspirations (Newcastle, UK; Rotterdam, Netherlands; Portland, Oregon USA; and Ningbo, China). This is the first time an IAT about BGI has focused on professional stakeholders, and the first comparative study of the implicit and explicit perceptions that professional stakeholders have of blue-green and grey infrastructure, and, hence, presents a novel exploration of whether stated preferences for BGI align with unconscious perceptions. It is also the first study to explore professional stakeholders' explicit perceptions of the attractiveness, tidiness, safety usefulness, valuableness, and necessity of blue-green and grey infrastructure. The IAT contributes additional insight into underlying attitudes that are more entrenched in respondents' value systems and cannot be captured by explicit tests, by removing many of the external influences and self-presentation effects (for example, social desirability bias) that affect explicit tests. Implicit attitudes have been little studied in the flood and water management discipline, yet may play a key role in influencing overarching attitudes towards BGI, and improving our understanding of potential disconnects between positive attitudes towards blue-green spaces and behaviours around them (O'Donnell *et al.* 2020a).

Blue-green and grey infrastructure are perceived positively by the sample population, suggesting that they are valued components of landscapes, albeit for different reasons. Stated preferences therefore align with automatic preferences assessed by the IAT. Overall, respondents implicitly and explicitly prefer BGI, and regard it as safer, tidier, more attractive, useful, valuable, and necessary. This suggests a widespread acknowledgement of the functionality (or multifunctionality) of BGI and benefits beyond aesthetic value. As an example, BGI may be regarded as of greater necessity when compared with grey infrastructure due to its ability to reduce vulnerability to other climate change risks beyond flooding, such as heat stress and water shortages. We can infer by the positive perceptions of BGI expressed by the professional stakeholders in this study that their personal perceptions are not barriers to implementation of BGI in their respective cities, as previously assumed (O'Donnell *et al.* 2017, Shandas *et al.* 2019), and other technical and socio-political factors are slowing down BGI progress. However, concerns over the safety of BGI expressed by 50 per cent of the Ningbo respondents may be a barrier to future implementation of blue-green systems. The individual positive explicit perceptions of grey infrastructure, nonetheless, suggest that integrated blue-green and grey systems may be preferable for professional stakeholders to incorporate into urban water management and climate change adaptation strategies. This is based on inferred experts' perceptions that resilience against future environmental threats cannot be achieved by traditional grey infrastructure systems alone, and that combinations of blue-green and grey infrastructure can improve system performance, increase urban climate adaptation, and further enhance urban environments and quality of life for citizens. Exploring implicit perceptions of integrated systems of blue-green–grey infrastructure designed to address climate change adaptation objectives is an important direction for future research.

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Appendices

Appendix 1
Feeling thermometers investigating how safe, attractive, tidy (or maintained in the US version), useful, valuable, and necessary respondents believe blue-green infrastructure is.

N.B. The same six feeling thermometers were used to investigate explicit perceptions of grey infrastructure, substituting 'blue-green' with 'grey' infrastructure.

Please indicate on the feeling thermometers how 1) safe, 2) attractive, 3) tidy, 4) useful, 5) valuable and 6) necessary you feel blue-green infrastructure is. Please click anywhere on the feeling thermometer to activate the slider, and then drag the slider to the point that best reflects your feelings.

1. Please indicate on the feeling thermometer how safe you feel blue-green infrastructure is.

0 20 40 60 80 100

Unsafe Safe

○ Prefer not to answer

2. Please indicate on the feeling thermometer how attractive you feel blue-green infrastructure is.

0 20 40 60 80 100

Unattractive Attractive

○ Prefer not to answer

3. Please indicate on the feeling thermometer how tidy you feel blue-green infrastructure is.

0 20 40 60 80 100

Untidy/unmaintained Tidy/maintained

○ Prefer not to answer

4. Please indicate on the feeling thermometer how useful you feel blue-green infrastructure is.

0 20 40 60 80 100

Useless Useful

○ Prefer not to answer

5. Please indicate on the feeling thermometer how valuable you feel blue-green infrastructure is.

0	20	40	60	80	100
Not valuable					Valuable

○ Prefer not to answer

6. Please indicate on the feeling thermometer how necessary you feel blue-green infrastructure is for flood risk and stormwater management:

0	20	40	60	80	100
Unnecessary					Necessary

○ Prefer not to answer

Appendix 2
Implicit Association Test (IAT): blue-green vs. grey infrastructure

Information presented to respondents prior to competing the IAT, followed by the stages of the IAT, and an example where the IAT score is presented and explained.

You will be presented with sets of words to classify into groups using the 'E' and 'I' keys on the keyboard.

Positive words	Attractive, Clean, Healthy, Reliable, Safe, Useful, Valuable
Negative words	Dangerous, Dirty, Ugly, Unhealthy, Unreliable, Useless, Worthless
Blue-green infrastructure	Green roof, Green wall, Retention pond, Rain garden, Street tree, Swale, Wetland
Grey infrastructure	Combined sewer overflow, Culvert, Sewer, Storm drain, Subsurface pipe, Underground storage tank, Storm sewer

Tips for completing the IAT:

- Two labels at the top will tell you which words or images go with each key.
- Keep your index fingers on the 'E' and 'I' keys to enable rapid response.
- Each word has a correct classification. If you classify the word incorrectly a red 'X' will appear and you will need to press the correct key to move on.
- The test uses response times so please try to respond as fast as possible.

IAT stage 1

Blue-green	Grey

- Keep your index fingers on the **E** and **I** keys of your keyboard.
- Words or images representing the categories at the top will appear one-by-one in the middle of the screen.
- When the item belongs to the category on the left, press the **E** key; when the item belongs to the category on the right, press the **I** key.
- Items belong to only one category.
- If you make an error, an **X** will appear. Fix the error by hitting the other key.

Press the **space bar** to begin **Stage 1**.

If the **E** and **I** keys do not work, click the mouse inside the white box and try again.

IAT stage 2

Positive words	Negative words

- Keep your index fingers on the **E** and **I** keys of your keyboard.
- If you make an error, an **X** will appear. Fix the error by hitting the other key.

Press the **space bar** to begin **Stage 2**.

If the **E** and **I** keys do not work, click the mouse inside the white box and try again.

IAT stage 3

Blue-green or Positive words	Grey or Negative words

- Keep your index fingers on the **E** and **I** keys of your keyboard.
- If you make an error, an **X** will appear. Fix the error by hitting the other key.

Press the **space bar** to begin **Stage 3**.

If the **E** and **I** keys do not work, click the mouse inside the white box and try again.

IAT stage 4

Grey | Blue-green

- Keep your index fingers on the **E** and **I** keys of your keyboard.
- If you make an error, an **X** will appear. Fix the error by hitting the other key.

Press the **space bar** to begin **Stage 4**.

If the **E** and **I** keys do not work, click the mouse inside the white box and try again.

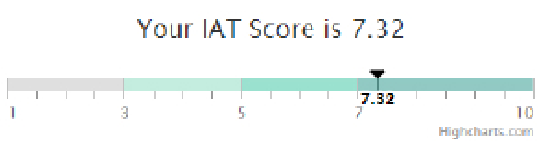
IAT stage 5

Grey or Positive words | Blue-green or Negative words

- Keep your index fingers on the **E** and **I** keys of your keyboard.
- If you make an error, an **X** will appear. Fix the error by hitting the other key.

Press the **space bar** to begin **Stage 5**.

If the **E** and **I** keys do not work, click the mouse inside the white box and try again.



Your IAT score suggests that you have a preference for *Blue-green infrastructure.*

Information on Implicit Association Tests

The IAT software automatically calculates your implicit (subconscious) preference for blue-green or grey drainage infrastructure based on the speed of your response to the IAT questions and pairing of blue-green or grey, and positive or negative, words. Pairings with faster responses and fewer errors are interpreted as more strongly associated in memory than more difficult pairings (slower responses).

We are interested in comparing your implicit preference with your explicit preference. We can determine this from your responses to the slider bars. Unfortunately, we are not able to report your explicit preferences in real time as the scores need to be calculated off-line. However, we will email your explicit preference to you once this has been calculated.

The spontaneous nature of implicit association tests removes many of the external influences associated with measuring explicit attitudes, and negates issues of social desirability bias, self-enhancement bias, and self-ignorance bias common with explicit tests. IATs have been used to investigate a range of attitudes, including nuclear power (e.g. Truelove et al., 2014) and climate change (Beattie and McGuire, 2012), carbon footprint products (Beattie and Sale, 2009), connections with nature (Bruni and Schultz, 2010), GM foods (Spence and Townsend, 2006) and racial prejudices (e.g. Greenwald et al., 1998).

For more information on the Blue-Green Futures project please see our project blog or contact one of the project team:
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Appendix 3

Individual respondent scores in the Feeling Thermometer tests.

TD = Thermometer Difference, BG = Blue-Green, G = Grey, Ne = Newcastle, P = Portland, R = Rotterdam, N = Ningbo.

Thermometer scores have been normalised to a −2 to +2 scale to be consistent with the IAT D-score.

City	Feeling thermometer scores												
	TD score	Safety BG	Safety G	Attractiveness BG	Attractiveness G	Tidiness BG	Tidiness G	Usefulness BG	Usefulness G	Valuableness BG	Valuableness G	Necessity BG	Necessity G
Ne	0.56	1.20	1.40	1.60	−1.20	1.40	1.60	1.80	1.20	1.36	1.40	1.80	1.40
Ne	−0.08	2.00	2.00	1.52	0.40	0.36	2.00	2.00	2.00	2.00	2.00	2.00	1.96
Ne	0.89	1.80	1.28	1.88	−0.16	1.64	−0.04	2.00	1.80	1.56	1.12	2.00	1.56
Ne	1.55	1.56	1.08	1.64	−1.20	1.12	−1.40	2.00	−0.32	2.00	1.24	2.00	−0.44
Ne	0.69	2.00	2.00	1.80	−1.20	1.80	1.64	1.76	1.60	2.00	1.20	1.24	1.20
Ne	0.95	1.92	1.16	2.00	−1.68	0.68	1.16	2.00	1.16	2.00	1.12	2.00	2.00
Ne	0.45	1.24	1.16	1.20	−1.20	0.44	0.76	1.60	1.16	1.24	0.72	0.84	1.24
Ne	0.55	2.00	1.60	2.00	−0.12	1.60	1.16	1.60	1.64	2.00	1.64	2.00	2.00
Ne	0.41	1.64	1.08	2.00	−1.28	0.48	0.68	1.28	1.72	1.48	1.68	1.16	1.68
Ne	−0.23	1.64	1.96	0.36	−0.48	0.32	1.96	1.96	2.00	1.84	2.00	1.96	2.00
Ne	1.55	1.92	0.72	2.00	0.32	1.84	0.32	2.00	–0.44	2.00	−0.48	2.00	2.00
Ne	1.09	1.32	1.76	1.84	−1.88	0.48	0.16	2.00	1.52	2.00	0.80	2.00	0.72
Ne	0.92	1.80	1.44	1.40	–0.60	1.40	0.08	2.00	1.60	1.44	0.88	2.00	1.12
Ne	0.27	1.20	2.00	2.00	0.00	2.00	1.60	2.00	2.00	2.00	2.00	2.00	2.00
P	1.33	1.76	1.28	1.44	−2.00	0.44	1.00	2.00	0.56	2.00	0.40	2.00	0.40
P	1.40	1.72	−0.08	1.40	−1.32	0.24	0.80	2.00	1.00	1.72	0.08	1.84	−1.00
P	−0.06	1.16	0.32	0.72	−0.12	−0.92	1.16	0.76	2.00	1.56	1.20	2.00	1.08
P	0.19	2.00	2.00	1.16	−2.00	−0.44	0.40	0.80	2.00	1.16	1.16	0.40	0.36
P	1.29	2.00	1.12	2.00	−2.00	0.68	0.36	2.00	1.08	2.00	0.36	2.00	2.00
P	1.13	1.80	−0.44	1.56	−1.92	1.48	1.20	2.00	–0.84	2.00	−0.80	2.00	−1.28
P	1.04	2.00	1.12	1.16	−1.28	0.80	1.24	2.00	1.16	2.00	1.12	2.00	0.36
P	0.20	1.60	1.60	1.64	0.72	1.16	1.68	2.00	1.60	2.00	1.64	1.64	1.60
P	1.47	1.56	0.40	2.00	−0.80	0.64	0.36	2.00	0.72	2.00	−0.44	2.00	1.16
R	0.79	1.72	1.60	2.00	−1.24	0.80	1.20	2.00	2.00	2.00	0.60	2.00	1.60
R	0.63	1.64	1.56	1.16	−1.52	0.00	0.72	1.20	0.76	1.24	0.72	1.16	0.36
R	0.53	1.60	0.88	1.56	−0.12	1.00	0.32	1.08	1.16	1.24	0.76	0.88	1.16
R	0.21	1.12	0.32	0.76	−0.12	0.36	0.36	0.72	1.16	1.12	1.16	1.16	1.12

City	Feeling thermometer scores												
	TD score	Safety BG	Safety G	Attractiveness BG	Attractiveness G	Tidiness BG	Tidiness G	Usefulness BG	Usefulness G	Valuableness BG	Valuableness G	Necessity BG	Necessity G
R	0.14	1.64	1.56	1.44	0.68			1.48	1.92	1.52	1.48	1.76	1.52
R	0.16	1.60	1.12	2.00	0.32	−0.04	1.16	1.16	1.16	1.16	1.12	1.12	1.16
R	0.37	0.24	1.28	1.64	0.24	0.92	−0.12	1.36	1.28	1.20	1.00	0.88	0.32
R	0.97	1.16	−0.08	1.20	0.00	0.36	1.12	2.00	0.40	2.00	0.32	2.00	1.16
R	−0.23	0.00	0.80	1.00	−0.80	−1.20	1.60	1.20	1.20	1.60	0.40	0.40	1.20
N	0.48	0.12	1.60	1.68	−1.64	1.64	−1.60	−0.04	1.32	1.20	1.52	1.00	1.52
N	0.92	1.04	−0.68	1.40	−0.60	0.84	−0.92	2.00	1.44	1.20	1.44	1.16	1.44
N	1.42	1.64	−0.16	1.48	0.16	1.32	−1.04	0.68	0.52	1.88	0.56	1.88	0.32
N	0.29	0.80	1.72	1.96	−1.04	2.00	−1.12	1.24	2.00	0.56	2.00	0.72	2.00
N	0.56	−0.24	0.00	−0.08	−1.36	0.64	−0.56	1.00	0.88	1.76	1.36	1.04	0.44
N	1.41	1.60	−1.48	1.52	−2.00	1.28	−1.56	1.64	1.20	2.00	1.08	2.00	1.20
N	0.70	1.32	−2.00	1.76	−0.96	1.20	0.00	1.40	−0.08	0.68	−0.20	1.08	0.00
N	0.49	2.00	2.00	0.16	−1.32	1.96	−0.68	2.00	−1.04	−0.20	2.00	−0.16	1.84
N	−0.36	−0.80	0.72	−0.56	0.00	0.48	0.68	0.24	0.16	1.00	0.68	0.16	0.44

Appendix 4
Individual respondent scores in the Implicit Association Test (IAT).

City	IAT D-score
Newcastle	0.44
Newcastle	0.14
Newcastle	0.70
Newcastle	2.00
Newcastle	0.54
Newcastle	1.04
Newcastle	0.20
Newcastle	0.52
Newcastle	0.31
Newcastle	0.56
Newcastle	2.00
Newcastle	1.31
Newcastle	1.99
Newcastle	0.78
Portland	1.10
Portland	1.52
Portland	0.90
Portland	1.57
Portland	0.84
Portland	1.40
Portland	1.22
Portland	−0.47
Portland	1.15
Rotterdam	0.20
Rotterdam	0.87
Rotterdam	0.62
Rotterdam	1.02
Rotterdam	1.49
Rotterdam	1.09
Rotterdam	1.07
Rotterdam	1.16
Rotterdam	1.18
Ningbo	0.47
Ningbo	0.48
Ningbo	0.53
Ningbo	0.27
Ningbo	1.26
Ningbo	0.75
Ningbo	0.80
Ningbo	0.74
Ningbo	0.84

Appendix 5
Correlations between explicit attributes of Blue-Green Infrastructure (BGI) and Grey Infrastructure (feeling thermometer data).

A Spearman's rank-order correlation was run to determine the relationships between the six attributes of BGI, and six attributes of grey infrastructure. Shaded cells represent correlations that are significant at the 0.05 level (2-tailed).

BGI

	Safety	Attractiveness	Tidiness	Usefulness	Valuableness	Necessity
Safety		*r* = 0.154 *p* = 0.669	*r* = 0.145 *p* = 0.372	*r* = 0.460 *p* = 0.002	*r* = 0.390 *p* = 0.012	*r* = 0.410 *p* = 0.008
Attractiveness			*r* = 0.429 *p* = 0.006	*r* = 0.308 *p* = 0.052	*r* = 0.352 *p* = 0.024	*r* = 0.371 *p* = 0.017
Tidiness				*r* = 0.230 *p* = 0.154	*r* = 0.081 *p* = 0.620	*r* = 0.111 *p* = 0.492
Usefulness					*r* = 0.610 *p* = 0.000	r = 0.657 *p* = 0.000
Valuableness						*r* = 0.816 *p* = 0.000

Grey Infrastructure

	Safety	Attractiveness	Tidiness	Usefulness	Valuableness	Necessity
Safety		*r* = 0.004 *p* = 0.980	*r* = 0.305 *p* = 0.055	*r* = 0.567 *p* = 0.000	*r* = 0.576 *p* = 0.000	*r* = 0.462 *p* = 0.002
Attractiveness			*r* = 0.194 *p* = 0.230	*r* = 0.178 *p* = 0.266	*r* = 0.173 *p* = 0.280	*r* = 0.188 *p* = 0.239
Tidiness				*r* = 0.291 *p* = 0.069	*r* = 0.071 *p* = 0.664	*r* = 0.205 *p* = 0.205
Usefulness					*r* = 0.603 *p* = 0.000	*r* = 0.456 *p* = 0.003
Valuableness						*r* = 0.495 *p* = 0.001

Appendix 6
Explicit preferences for Blue-green and Grey Infrastructure calculated using different selections of evaluative attributes.

Evaluative attributes	*TD score*	*Range*
Safety, attractiveness, tidiness*, usefulness, valuableness and necessity	0.66 (0.52)	−0.36 to 1.55
Safety, attractiveness, tidiness*	0.74 (0.61)	−0.60 to 2.00
Safety, attractiveness, tidiness*, necessity	0.66 (0.50)	−0.65 to 1.40
Safety, tidiness*, necessity	0.33 (0.58)	−1.47 to 1.59

Standard deviation is given in parentheses, $n = 41$.
*Tidiness or maintained in the US tests, which is common vocabulary to describe the appearance of Blue-green Infrastructure.