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# Mind the perception gap: The impact of bus rapid transit infrastructure on travelers' perceptions of affective subjective well-being

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ABSTRACT

Over the past 20 years, bus rapid transit (BRT) has been increasingly promoted as an affordable way to improve public transit services in cities around the world. In many places, however, BRT projects have faced community opposition for a range of reasons, such as concerns around loss of private transport space and parking, demand for improved pedestrian and cycle infrastructure, and impacts on streetscapes. This research informs the selection of BRT infrastructure options by considering the perspective of travelers' affective subjective well-being (SWB). Specifically, in a randomized control trial framework, individuals are presented with photo-simulations of various BRT infrastructure alternatives, and report their psychometric indicators of happiness or perceived safety. We test this approach using an urban corridor approximately 2 km in length in Boston, exploring the impact of 65 different BRT infrastructure alternatives. We find that: (1) compared to regular bus services, a 'standard BRT' consisting of a painted bus lane and the addition of a cycle lane significantly enhances SWB; (2) an 'SWB infrastructure' option that replaces car parking with improvements for cyclists and pedestrians and adds street amenities further enhances SWB; and, (3) the BRT infrastructure elements most effective in enhancing affective SWB for users of all transport modes are the addition of green spaces, improvement of crosswalks, and provision of more space for pedestrians and cyclists. This study shows the importance, for citizens' emotional well-being, of moving from a traditional bus-only approach to multi-modal BRT infrastructures. Future research could integrate this technique into actual participatory planning processes to select the most effective BRT infrastructure in corridors of specific interest, in Boston and beyond.

## 1. Introduction

Bus Rapid Transit (BRT) has been adopted globally as an affordable and low-carbon emission option for fast and reliable road-based public transit (Lindau et al., 2014; Baghini et al., 2014). From its first full implementation in 1982 in Curitiba, Brazil, BRT now provides mobility for more than 31.5 million trips a day in 182 cities across five continents (Global BRT Data, 2020). Despite this somewhat rapid uptake, BRT implementation has often proven a challenge (e.g., GAO, 2011; GAO, 2012; Hidalgo and Carrigan, 2010). While traditional cost-benefit appraisals based on evaluations of objective well-being generally support BRT, it still often faces

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considerable community opposition that can slow down the progress of a project, or even stop it altogether (Lindau et al., 2014). Research in both the Global North and South suggests that this opposition is often based on stakeholders' negative perceptions of BRT projects, due to factors such as buses being perceived as a low-quality transport mode or a project occupying street space that could instead be used for other purposes perceived as more valuable (e.g. vegetation, pedestrian space, private traffic, parking) (Lindau et al., 2014; Zegras et al., 2016). In recent years, increasing focus has been placed on understanding community members expectations and perceptions of transport infrastructure projects, to enhance the likelihood of project acceptance, meet demand expectations, and improve overall project cost-effectiveness (Guzman, et al., 2022). Nonetheless, infrastructure design itself has traditionally remained relatively neglected as a central consideration of BRT policy and practice. In recent years, planners and designers have come together to address some of these concerns by promoting best practice design guidelines for BRT infrastructure (see, for instance, nacto.org). However, this expert-centered method draws little from evidence of BRT infrastructure's impacts on communities' subjective well-being. In part, this is due to a lack of methodological strategies to identify, from a wide range of infrastructure options, evidence-based designs that enhance the subjective well-being of the communities impacted by a project and its potential alternatives. A better understanding of the impact of such alternatives may help to build stakeholder support, and allow for the realization of more and higher-quality BRT projects.

An increasing body of empirical evidence documents the link between the quality of individuals' urban environments and their assessment of their own subjective well-being (hereafter SWB) (e.g. (Ambrey, 2016); Helliwell and Putnam 2004; Krefis et al., 2018; MacKerron and Mourato, 2013; Navarrete-Hernandez and Laffan, 2019). Since BRT infrastructure leads to significant changes in the built environment and distribution of road space, its implementation is expected to considerably alter the SWB of travelers (whether positively or negatively), in turn conditioning preferences for different transport infrastructure options (Abou-Zeid, 2009; Ettema, et al., 2010). In general, we would expect these impacts on SWB to vary, for instance, by user, by mode, and by travel purpose. For example, car drivers may experience more traffic and therefore increased stress due to BRT infrastructure; bus passengers, on the other hand, might enjoy expedited travel in a pleasant and peaceful environment; cyclists, in turn, might feel safer when BRT projects incorporate a dedicated cycle lane (De Vos et al., 2013). Further studies also show that cycle lane infrastructure design affects cyclists' perception of safety (Gossling and McRae, 2022; Rossetti et al., 2018; von Stülpnagel and Binning, 2022). Impacts extend beyond those traveling, as Speck (2012) highlights, since different affective outcomes of BRT infrastructure can be observed for residents, commuters, and business owners (p. 157). The evidence thus strongly suggests that there is a link between individuals' emotional responses and the infrastructure developments that impact their journeys and their surroundings.

While a burgeoning literature exists considering the relationships between mobility, transport infrastructure and SWB (see Chatterjee et al., 2020; Gossling and McRae, 2022; von Stülpnagel and Binnig, 2022; Rossetti et al., 2018), most of the studies to date use cross-sectional and observational designs, with a few using longitudinal data, weakening any claims of causality (Chatterjee et al., 2020, p. 28; Metcalfe and Dolan, 2012, p. 508). Moreover, to the best of our knowledge, no study directly analyzes the impact of BRT infrastructure on individuals' SWB. In this light, we have two aims: to identify the existence and degree of these causal impacts and, based on these findings, identify which BRT infrastructure configurations enhance communities' SWB benefits.

Specifically, we examine the causal impact of different BRT designs on two affective (i.e. emotion-based, as opposed to cognitive) SWB measures, reported levels of happiness and safety. To do this, we conduct a randomized control trial (RCT)[1] using photo-simulations of BRT infrastructure alternatives. We collected data in the field and online from 1,470 respondents and use those data in mixed-effects regressions. Our findings suggest that the implementation of standard BRT infrastructure, compared with a basic bus service, significantly enhances affective SWB. Affective SWB can be further enhanced for users of all transport modes by incorporating additional improvements, notably by replacing car parking with walking and bicycle spaces, and by incorporating street amenities. Substantively, our findings suggest that, to enhance travelers' affective SWB, BRT projects should move from a bus-centered to a mobility-centered infrastructure approach. Methodologically, our work provides insights on ways for identifying effective infrastructure options. Our image-based RCT approach can be further used by policy makers working in different geographical contexts to determine exactly which types of BRT infrastructure can enhance affective SWB in their communities.

## 2. Literature review

Three main bodies of literature have relevance for our study: 1) literature on the definition and measurement of well-being; 2) studies exploring the links between well-being and mobility; and, 3) studies exploring the links between the well-being of travelers and the built environment. Each of these relates directly to the topic covered in our study – emotional responses to transport infrastructure development within the built environment – and, taken together, they highlight the relevance of our study and show the importance of integrating our findings into the wider decision-making process. Finally, from these precedents, we summarize important considerations for our own study.

### *2.1. Defining and measuring Well-Being*

Although few would disagree that public policies should broadly aim to increase societal well-being, an intense debate revolves

[1] RCTs are a robust causal inference method that, by randomly assigning subjects to treatment or control conditions, fulfil all identification requirements – association, time order, and non-spuriousness – to yield causal conclusions about the impact of the treatment (independent variable) on a selected outcome (dependent variable) (Angrist & Pischeke, 2008).

around how, exactly, well-being can best be understood and measured (Kahneman et al., 1999; Layard, 2005; Forgeard et al., 2011). Current debate focuses on the most effective means of capturing objective and subjective conceptions of well-being, with three main approaches prevailing: preference satisfaction; the objective list; and 'mental state' approaches (Estes and Sirgy, 2017; Dolan and Metcalfe, 2012). Objective well-being is defined in terms of tangible quality of life indicators including material (e.g. income, housing) and social resources (e.g. education, health, security) (Western and Tomaszewski, 2016). Preference- and list-based methods aim to provide objective assessments of well-being (Helliwell and Barrington-Leigh, 2010). For the preference-satisfaction approach, well-being is conceived as a matter of desire fulfillment: well-being increases when an individual's preferences are satisfied. Under this rubric, income is often used as a preferred measurement technique, as a higher income increases an individual's capacity to consume preference-satisfying goods and services. The objective list approach proposes that certain characteristics can often be considered as objectively good or bad for a person. For example, having a strong education, sound health, or financial security are all considered positive characteristics. In this way, we can infer a person's well-being by measuring the person's list of objectively positive attributes.

Diener (2006) defines SWB as a combination of individuals' reports of emotions as they go about living their lives, and how they think about their life. SWB is commonly conceived in two ways: as eudemonic well-being, which refers to personal growth, purpose and meaning, and as hedonic well-being, referring to life satisfaction and positive and negative emotions (Rayman and Deci, 2001; Singleton, 2019; Vanhoutte and Nazroo, 2014; De Vos et al., 2013). It is this latter conception that will be the focus of the present study, as it reflects our expectation that bus infrastructure impacts the more pragmatic, immediate aspects of travel experience. From a hedonic SWB approach, cognitive SWB relates to one's life satisfaction, and is commonly measured through scales of personal satisfaction with life (e.g. five-item questionnaires) which can be on temporal bases (regarding the past, present, and future), or regarding specific aspects of life (e.g. personal finances, friendships, health) (see Margolis et al., 2018). In contrast, affective SWB, the focus of this study, reports an individual's affect, emotion, or mood, drawing on Bentham's utilitarian view that the relevant factors for people's well-being are experiences of pleasure and pain (Collard, 2006; Graham and Nikolova, 2015). Nowadays, affective SWB is measured through reports of positive and negative emotions, such as how happy, fearful, calm, sad or angry a person feels at any given moment. For Helliwell and Barrington-Leigh (2010), measurements of SWB would ideally complement more traditional accounts of welfare and well-being, while Metcalfe and Dolan (2012, p. 508) propose that researchers and public policies should consider SWB as the only and true measure of people's experiences, rather than objective accounts, which they perceive as measuring well-being indirectly. Despite differences in opinion around how they might be used in practice, people's subjective experiences are increasingly recognized as important factors to account for in any relevant measurement of well-being for public policy.

### 2.2. *Utility, subjective Well-Being and mobility*

Transport planning has traditionally adopted methods related to satisfaction of travel and cost-benefit evaluations (De Vos et al., 2013). Building on welfare economics, these evaluations are based on the idea of *decision utility*, which attributes individuals' behaviors to weights of various objective factors. The actual individual experience from a person's travel choice is referred to as *experience utility*, while its forecast when used to make decisions in the future is referred to as *anticipated utility*. Research shows that the *decision*, *anticipated* and *experienced* utility often differ due to factors such as incomplete information and cognitive biases (Zanna, 2003). As such, Ettema et al. (2010) question the validity of decision utility, as it does not accurately estimate the outcome benefits of a travel choice, and so models based on this do not account for an individual's actual utility experienced when travelling. If the objective is to measure the actual benefits of travel (experienced utility) as a valid utility measure, rather than the process of travel decision-making (decision utility), then measures of SWB would prove more appropriate. In this sense, measurements of affective and cognitive SWB in travel evaluation are at least a useful complement to the current approaches of travel choice models and cost-benefit analyses used in transport planning (Abou-Zeid, 2009).

A growing body of transport research has emerged exploring the links between mobility and SWB, both affective and cognitive (Nordbakke and Schwanen, 2014). Chatterjee et al. (2020) argue that, due to its unavoidable and everyday nature, traveling – an act that demands substantial time and resources from users – has a significant impact on an individual's SWB, both during the journey time and beyond. Metcalfe and Dolan (2012) further argue that, since research shows a strong link between SWB ratings and subsequent behavior (Di Tella et al., 2003; Bray and Gunnell, 2006), even from a traditional utility theory perspective, SWB remains a relevant consideration for transport development; SWB explains people's observed behavior as reflecting their true preferences, and thus offers a valid measurement of the underlying utility a person derives from transportation activities. While past SWB studies have covered commuting satisfaction (i.e. measures of cognitive SWB), and its spillover into other life domains, this study focuses on the less explored impacts of transport on users' affective experiences.

Studies considering the link between transportation and affective SWB can be classified into three areas: 1) overall commuting experiences; 2) impact of transport mode on affects; and, 3) impact of personal traits on affects (Chatterjee et al., 2020). Studies in the first area show commuting to be one of the least pleasurable activities of the day, eliciting the least positive and the most negative affect scores (Kahneman et al., 2004; Mokhtarian et al., 2015; Lancée et al., 2017; ; White and Dolan, 2009). This negative affect outweighs any objective travel considerations, including trip purpose, transport mode, and travel distance (Ory and Mokhtarian, 2005). Studies also show that commuters' stress increases with commute duration (Morris and Guerra, 2015), crowding (Lundberg, 1976) and delays (Gatersleben and Uzzell, 2007), but decreases with schedule predictability (Evans et al., 2002), enhanced public transport service quality (Wenner et al., 2005), and for workers with more flexible schedules (Lucas and Heady, 2002). Further corroboration of this decrease in stress can be seen in studies showing that personal enjoyment of the commute and increased flexibility of commuting mode are associated with lower feelings of anxiety (Mao et al., 2016; De Vos et al., 2016; Handy and Thigpen, 2019; Ory et al., 2004). The experience of commuting has significant spillover effect into the SWB, both affective and cognitive, of subsequent activities (Christian, 2012; Hilbrecht et al., 2014; Nie and Souza-Poza, 2018). This includes time spent at work (Abou-Zeid and Ben-Akiva, 2011 Morris and Zhou, 2018; Friman et al., 2017), satisfaction with social contacts (Delmelle et al., 2013; Kroesen, 2014), and leisure time (Wheatley, 2014). These long-lasting impacts of commuting on affective SWB makes it imperative for transport policy to focus on enhancing the affective experience of users.

The second area of studies compares the affective SWB experience across different modes of transport. In a systematic review, Norgate et al. (2020) report a significant relationship for commuters, who experience higher levels of affective SWB for active modes, such as biking and walking, and lower levels for public transport and car commuting (see e.g. Friman et al., 2017; Gatersleven and Uzzell, 2007; LaJeunesse and Rodríguez, 2012; Legrain et al., 2015; Rissel et al., 2016; St-Louis et al., 2014). A posited primary mechanism behind this link is that active commuting's higher physical activity results in a more positive mood (Ekkekakis et al., 2008; Gatersleben and Uzzell, 2007; Humphreys et al., 2013). Moreover, Fordham et al. (2017) report that, for cyclists and pedestrians, positive affective SWB spills over into an individual's positive feelings and overall life satisfaction. Car users have been found to experience higher commuting satisfaction than those traveling by public transport, a link that may be explained by positive feelings of independence, control and prestige (Chatterjee, 2020). Morris and Guerra (2015) conclude that, across all daily activities and transport modes, total affect (a combination of negative and positive affect) is lowest for those traveling by bus. Given the established link between SWB and behavior (Metcalfe and Dolan, 2012), this likely acts as a deterrent towards a wider adoption of buses as a main transport mode, and may provide an explanatory factor for opposition to BRT projects.

A final body of empirical studies explores the link between travelers' affective SWB and their demographics. Research shows that commuters' SWB depends on gender and age; Stutzer and Frey (2008), for example, observe that affective SWB is more likely to be negatively impacted by commuting for women, while Wener et al. (2005) observe that women experience more stress when commuting. Graham et al. (2018) report that having reduced commuting options disproportionally impacts the affective SWB of older adults by decreasing opportunities for leisure, social, and recreational activities (see also Banister and Bowling, 2004; Loukaitou-Sideris, 2014;Nordbakke and Schwanen, 2014; Vlugt et al., 2019). Older adults' affective SWB also declines with low-quality and low-frequency public transport provision and with high travel costs, for similar reasons (Lättman et al., 2019; Nordbakke and Schwanen, 2015).

Taken together, these findings may present a relevant factor in explaining negative views towards projects that provide bus services, including among more vulnerable user groups, such as older adults and women. The commuting experience impacts an individuals' affective SWB both during and after traveling, and those traveling by bus face the most negative emotional experiences. Given the link between affective SWB and behavior, and the fact that people tend to remember their most intense emotions (Pedersen et al., 2011), the negative affective SWB caused by bus commutes may naturally lead to negative reactions towards infrastructure that fosters the growth of bus services – especially if that infrastructure takes space previously used for modes perceived as 'more desirable' (i.e. leading to higher affective SWB). This highlights the relevance of enhancing the affective SWB experience of BRT projects for bus users in particular, and commuters in general, as an aim of a transport policy aimed at facilitating the growth of effective, high-quality bus services.

Importantly, most of the studies cited above rely on cross-sectional and observational designs, with only a small number using longitudinal data. As such, we have little causal evidence of the relationship between affective SWB and mobility. Chatterjee et al. (2020, p. 28) and Metcalfe and Dolan (2012, p. 508) therefore make an urgent call for future transportation studies to use experimental or quasi-experimental designs that randomize different interventions to more strongly substantiate causal claims.

### 2.3. The link between the built environment and individuals' well-being

The influence of built environment conditions on individuals' affective SWB is well recognized in environmental psychology literature.[2] A rapidly growing body of literature specifically examines the impact of green spaces on affective SWB (Krefis et al., 2018). Correlational and causal evidence shows that increased urban green space results in higher levels of happiness, safety and life satisfaction ((Ambrey, 2016; MacKerron and Mourato, 2013; Navarrete-Hernandez and Laffan, 2019; Pfeiffer and Cloutier, 2016; Pfeiffer et al., 2020) and lower levels of depression, stress, and anxiety (De Vries et al., 2003; Maas et al., 2009; Van den Berg et al., 2010, 2014). Navarrete-Hernandez and Laffan (2019), for example, use photo-simulations in an RCT setting to demonstrate that the incorporation of green infrastructure at the street level improves perceptions of happiness and safety while reducing stress, with benefits increasing with the size of the green intervention. Similar results can be seen in Van den Berg et al.'s (2014) study, which shows that large green spaces have a restorative stress impact when compared with urban environments without vegetation. This is in line with the findings of Kim et al.'s (2010) neuroscientific study, in which functional magnetic resonance techniques demonstrate that exposure to images of green spaces activates the basal ganglia, a brain area associated with positive emotions such as happiness, while urban images activate the amygdala, a brain area associated with feelings of fear and danger. Ramirez et al. (2021) further show that the presence of parked cars in streets lowers perceptions of safety. Further studies on walking in natural versus urban environments show that green spaces increases happiness and reduce emotions of anger (Hartig et al., 2003; Nisbet and Zelenski, 2011). These studies clearly demonstrate the link between the features of a built environment and an individual's emotional state.

[2] Another related body of studies looks at the relationship between residential environments and SWB. Correlational evidence indicates that the presence of high pollution, high density, degraded social housing, and poorly connected neighborhoods have a detrimental impact on individuals' affective SWB (Cunado & Gracia, 2013; Vemuri, 2009; Morrison, 2007; Smyth et al., 2008; Dang et al. 2017), while mixed uses, including the presence of commercial areas, enhance affective SWB (Cao, 2016; Helliwell and Putnam, 2004; Schwanen and Wang, 2014).

A more recent body of literature explores the relationship between transport infrastructure conditions and travelers' affective SWB, with most studies focusing on bicycle infrastructure. For instance, Echiburú et al. (2021) find that built environment conditions have a significant effect on cyclists' feelings of pleasure when traveling in Santiago de Chile, while Rossetti et al. (2018) use photo-simulations to find that perceived safety increases with increased cycling infrastructure, restricted speed limits and decreased public transport. Moreover, the latter authors estimate that cyclists' route-selection behavior is dependent on the perceived safety of a given route. Stulpnagel and Binning (2022) show that cycle lanes with a strong visual separation between car parking and traffic, as well as bicycle pictograms, increase perceived safety for cyclists. Similarly, Gossling and McRae (2022), in a study of bicycle infrastructure in Berlin, show the importance of a wide cycle lane separated from motorized and pedestrian traffic in enhancing perceived safety, with a further significant impact found from the removal of parking adjacent to bicycle lanes.

While these studies are restricted to cycling, and for the most part rely on observational data, they suggest that transport infrastructure has an effect in determining travelers' affective SWB. Indeed, Chaterjee et al. (2020) note that, beyond cycling infrastructure, this link remains overall largely unexplored. Reaching a deeper understanding of this causal relationship remains central to our study.

### 2.4. Considerations regarding the measurement of affective SWB

A challenge encountered throughout the social sciences when measuring affective SWB comes from the diversity of approaches used (Mackenroon and Mourato, 2013). In many studies, affective SWB is typically measured by asking individuals to rate their experience of different affective states at that exact moment (e.g., "How happy are you right now?"), over a specific time frame, or under certain circumstances (Diener et al., 2010; Luhmann, 2017). However, these studies tend to lack a standardized, reliable means of defining and measuring affective SWB (Kalmijn et al., 2010). This issue can be resolved by employing psychometric scales when possible, which provide standardized measurements that have passed validity, reliability and normalization checks for emotional quantification. Various psychometric scales are available including one-dimensional approaches such as the Positive and Negative Affect Schedule (PANAS) (Watson et al., 1988), or two-dimensional approaches like the Swedish Core Affect Scale (SCAS) (Västfjäll et al., 2002) or the Scale of Positive and Negative Experience (SPANE) (Diener et al., 2010). While some of these instruments are restricted to temporal scales, or to specific emotions or population groups, PANAS, given its long tradition and different versions (e.g. PANAS-C, SF, X), allows for the direct measurement of specific emotions of the general population through simple direct questions. As such, it gives us a standardized measurement of an extended and independent range of specific emotions (Karim et al., 2011), including happiness, which can be compared with results in transport studies and other related fields. In this study, we opt to follow PANAS-X, which is a psychometric scale that has been employed in many studies, consisting of 60-item scales for positive and negative emotions. One of the advantages of this scale is that its dimensions have been reduced and standardized, meaning that researchers can use the entire psychometric scale, or only parts of it, with the scale retaining its functionality in both cases (Watson and Clark, 1994).

It is important to recognize that urban infrastructure may elicit several different positive and negative emotions. In this study, we choose to focus on two outcomes, due to their previously identified relevance in transportation analyses. These outcomes are perceived happiness (i.e. an emotional aspect of the sentiment of joviality, following the basic positive emotion scale according to PANAS-X) and perceived (lack of) safety (i.e. generally related to feeling afraid, scared, nervous, and other emotions associated with the basic negative sentiment of fear, following the basic negative emotion scale according to PANAS-X). Happiness is a positive emotion typically defined as feeling good, and having the sentiment of enjoying life (Layard, 2005). Central to our daily experience, happiness is one of the most widely studied emotions used to investigate the relationship between positive affective SWB and the built environment (Su et al., 2021; MacKerron and Mourato, 2013; Khaneman and Dearton, 2010; Hazer et al., 2018). We also measure individuals' reported feelings of safety, a key transport-related concern (Hine, 1996; Zegras et al., 2015), and a common measure of negative affective SWB in the photo-simulation literature (Jiang et al., 2017; Jorgensen and Hitchmough, 2002; Marquez and Soto, 2021; Rossetti, 2018). Feeling unsafe closely relates to the emotions of fear felt when an individual is concerned about damage to or loss of property, physical or mental harm, or even loss of life from external threats, risks, or dangers (Wills, 2014; Russell, 1999). Related studies in transportation include those considering pedestrianized streets (De Silva et al., 2017; Evers et al., 2014; Rišová and Sládeková Madajová, 2020), cycle lanes (Gårder et al., 1998; Jensen, 2008; Thomas and DeRobertis, 2013; Knight and Charlton, 2022), bus/car lanes (Cafiso et al., 2013), and the mobility environment (Keane, 1998; Loewen et al., 1993).

When considering SWB, we must also account for its temporal dimension. Recalled SWB fundamentally relies on an individual's recollection of past experiences, which can produce bias known as the 'peak-end rule.' Basically, when recalling an event, people tend to favor two emotional states: their most intense emotions felt during the event, and their emotions at the event's end. This recall is thus not representative of their true experience as a whole (Pedersen et al., 2011). In contrast, predicted SWB is one's estimated future emotional experience or satisfaction from an activity or event. For this, however, one often draws from and relies upon remembered SWB from comparable past experiences, thus carrying forward the 'peak-end rule' bias (Kahneman, 2000a; Wirtz et al., 2003). Furthermore, research shows that people similarly underestimate the duration and intensity of their emotional experience when predicting SWB (Wilson and Gilbert, 2003). Indeed, research on both remembered and predicted satisfaction for bus users has shown that people underestimate their actual emotional experience (Pedersen et al., 2011). While recalled and predicted SWB are useful measures for analysis – for instance when predicting future behavior – for the purpose of this study we have chosen to use observed SWB, recorded at the moment of an event or activity, as a representation of people's actual experienced emotions and satisfaction levels which, unlike predicted and recalled SWB, does not lead us to biases linked to memory.

## 3. Methods

We use a Randomized Control Trial (RCT) strategy to assess the causal impacts of different BRT infrastructure options[3] on travelers' affective SWB measures, and demonstrate an approach by which these findings can be integrated into the planning process. Our RCT (henceforth 'image-based RCT')[4] was developed using realistic photo-simulations through an on-line platform, with data collected in-person and remotely from October 29th, 2019 to January 15th, 2020.[5]

### 3.1. Study design

We gathered data on individuals' reported affective SWB in response to randomly allocated visual simulations of Summer Street, Boston, either before (control) or after (treatment) the incorporation of BRT transport infrastructure and related improvements (see Fig. 1). Control images were taken along Summer Street at approximately 85-meter intervals (as well as two close-up images portraying bus stop lighting and information displays) to capture the street's different urban contexts. Participants were presented an image of the street and asked to state their levels of happiness from 1 (not at all) to 10 (extremely) and perceived safety on scale from 1 (very unsafe) to 10 (very safe). The psychometric indicators of happiness are extracted from the Positive and Negative Affect Schedule (PANAS-X) (Watson and Clark, 1994), while the perceived safety indicator was derived from Stulpnagel and Binning (2022) and Gossling and McRae (2022). In both cases, we adopted scales from 1 to 10, drawing from psychology research which shows that scales of between 7 and 10 points provide the best indices of reliability, validity, and discriminating power, with scales of 10 being preferred by respondents to adequately express their feelings (Lee and Paek, 2014; Lozano et al., 2008; Kalmijn et al., 2010; Preston and Colman, 2000).

We used 24 groups of images taken along Summer Street, each including versions with and without the visual simulations incorporating BRT infrastructure. The images represent three types of infrastructure scenarios: (1) 'basic bus service', representing the current Boston bus service as a baseline; (2) 'standard BRT', consisting of painted bus lanes and non-painted cycle lanes; and, (3) 'improved BRT', pooling all additional infrastructure improvements. We further categorized the 'improved BRT' options into six investment areas (bus lanes, buses, bus stops, cycle lanes, pedestrian space, and amenities), in total creating 65 different BRT street configuration options. From this, we obtained 24 groups of comparable images, equal in all features aside from the BRT infrastructure intervention being tested.

### 3.2. Sampling and Photo-Randomization strategy

We collected data both remotely and in the field. In-the-field data collection was undertaken at three transport-related community meetings organized by the Boston Transportation Department. Additionally, we collected data over one day from people at a Boston subway station (Park Street). We chose this approach to test the validity of our method in different planning consultation settings. For remote data collection, we disseminated the website link through social media, and posted 450 placard advertisements inside buses to increase the likelihood of bus riders responding. The placards contained the URL and a scannable QR code leading to the landing page. As compensation, five Amazon vouchers (valued at 20 USD) were distributed at random among the participants.

At the survey landing page, participants completed an online registration and an electronic consent form, as well as a questionnaire about their socio-demographic information (descriptive statistics in Table 1). On average, participants took 4:57 min to rate the series of 24 images presented to them. Over the nearly three months of data collection, 1,470 people contributed 32,167 image ratings.

We used a double randomization technique to balance control and treatment groups (Navarrete and Laffan, 2019). First, we randomized the order of appearance of each group of images to be presented to each participant, to control for spillover or respondent 'fatigue effects', which have the potential to affect ratings from one picture to the next. Second, as in any RCT, we randomly assigned within each group of images only one BRT infrastructure intervention (treatment) or the baseline image (control) to be rated for every group of images shown, which means participants rate only one infrastructure alternative, while the others remain unknown.

We decided on this randomization of participants' rating of either the current conditions, standard BRT, or improved BRT for two reasons. The first was to avoid what is known in psychology as the "relative comparison" problem, in which simultaneously evaluating two ("comparing effect") or even three ("attraction effect") options might in itself influence the ratings of participants. For instance, if a participant rates the standard BRT alongside the current bus service, then this standard BRT option might look much more appealing, but if we show a third photo-simulation containing a line of trees, then the standard BRT option might receive a lower score. As such, it

[3] We use photo-simulation techniques to represent different BRT infrastructure designs. These techniques have been widely used in environmental psychology and urban planning research (Jorgensen et al., 2002; Kuo et al., 1998; Rodiek and Fried, 2005; Ruggeri et al., 2014) to measure preferences such as safety (Kuo et al., 1998; Jiang et al., 2017); happiness (Navarrete-Hernandez & Laffan, 2019), stress, and anxiety (Nejati et al., 2016: Van den Berg et al., 2014). These studies show photo-simulations to be an effective tool to enhance our understanding of people's SWB across different sites and design configurations.

[4] Random allocation of control and treatment images allows us to build two equally comparable groups with equal observable and non-observable characteristics on average. The impact of the treatment is obtained by calculating the differences between control and treatment averages (ATE: Average Treatment Effect), while observable and non-observable variables cancel out.

[5] The photo-simulations were run on https://urban-experiment.com; the research was approved by the institutional review board of the Massachusetts Institute of Technology (COUHES protocol 1909988474).

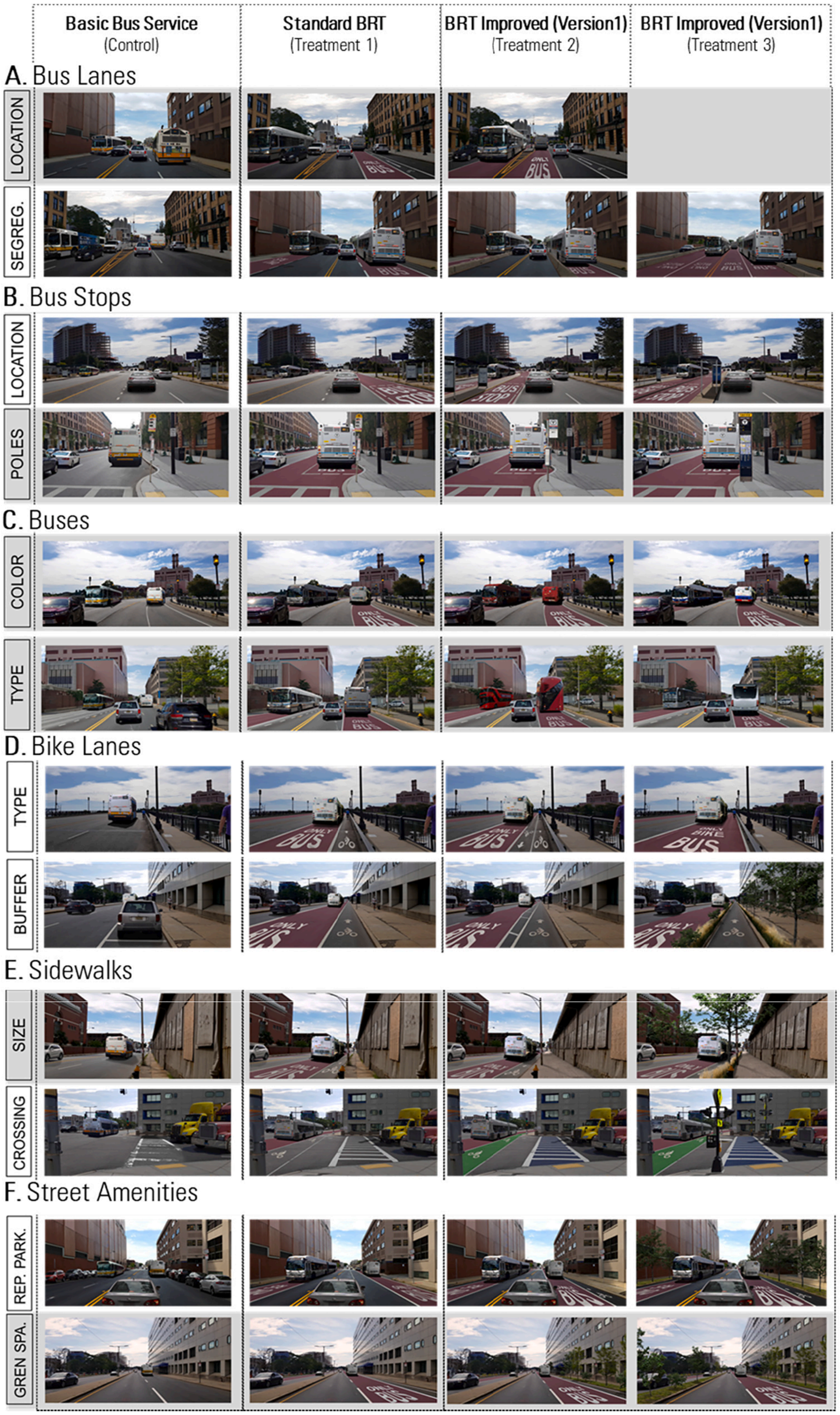


**Fig. 1.** Example of Photographic Simulations of Different BRT Infrastructure Options.

is possible that it is the comparison of the alternative itself that explains the changes of perceptions, and not the infrastructure improvement. To solve this problem, participants randomly rate only one infrastructure alternative, while the others remain unknown. Our second reason is that one condition of causal inference is the elimination of confounding explanatory factors. We achieve this by randomly assigning participants to control or treatment conditions (in our case – control: current bus service; treatment 1: standard

**Table 1**
Sample Descriptive Statistics (n = 1470).

| Category | | N | Percentage |
|---|---|---|---|
| **Country (US)** | | 1261 | 85.84% |
| **Gender (Female)** | | 787 | 53.51% |
| **Age** | | | |
| | 18–30 | 578 | 39.32% |
| | 31–59 | 772 | 52.52% |
| | Over 60 | 120 | 8.16% |
| **Income** | | | |
| | <50,000 USD | 394 | 26.80% |
| | 50,001–100,000 USD | 366 | 24.90% |
| | >100,000 USD | 563 | 38.30% |
| | Prefer not to say | 147 | 10.00% |
| **Regular Commute Mode** | | | |
| | Car | 188 | 12.78% |
| | Bus/Train | 732 | 49.79% |
| | Bike | 237 | 16.13% |
| | Walk | 188 | 12.78% |
| | Other | 125 | 8.52% |
| **Public Transit Users** | | | |
| | Every day | 685 | 46.60% |
| | 2–3 times a week | 349 | 23.74% |
| | 2–3 times a month | 254 | 17.28% |
| | Only if no other option | 140 | 9.52% |
| | Never | 42 | 2.86% |
| **Experiment Access** | | | |
| | Website post | 110 | 7.48% |
| | Social media | 241 | 16.40% |
| | Email invitation | 431 | 29.32% |
| | Bus advertising | 464 | 31.56% |
| | Community meeting | 34 | 2.31% |
| | Interview | 43 | 2.93% |
| | Other | 147 | 10.00% |
| **Perception of Happienss** | | **Mean** | **S.D.** |
| | Busic Bus service | 4.85 | 2.32 |
| | Standard BRT | 5.85 | 2.36 |
| | Improved BRT | 6.19 | 2.38 |
| **Perception of Safety** | | | |
| | Busic Bus service | 5.64 | 2.54 |
| | Standard BRT | 6.43 | 2.37 |
| | Improved BRT | 6.73 | 2.35 |

BRT; and treatment 2: improved BRT). This allows for participants' characteristics, both observable and unobservable, to be by probability balanced for control and treatment groups, and as such have no explanatory effect on changes of perception. This presumption is tested through two strategies: balance tests, and robustness of results checks. In balance tests, we examine, for all observable covariates, that there is no systematic difference between participants' characteristics in control and treatment groups, and thus, by extension, it is assumed that other unobservable covariates would also be balanced. From 68 tests conducted, only three were significant at the 5% level, showing that randomization was successful (tables available on request), and we can therefore confidently derive causal predictions. The robustness checks (see Section 3.4.1) show that the addition of 11 relevant controls (all collected observable covariates) does not change our estimates when compared to the regression without controls. We can, therefore, confidently derive causal predictions.

### 3.3. Data

We analyze data from: (1) participants' background characteristics; (2) measures relating to the experimental conditions; and, (3) participants' happiness and safety perceptions. Participants' background characteristics include their age, gender, ethnicity, income, nationality, educational level, regular mode of commute and frequency of public transportation use. The experimental condition measures include treatment status, image group, image order, and means of accessing the experiment. Subjective perception measures represent the stated perceptions of happiness and safety for each image (for variable descriptions, see Table A1 in the Appendix).

### 3.4. Empirical strategy

Our interest is whether BRT infrastructure improves participants' affective SWB perceptions (measured as happiness and safety). We run separate models for the perception of happiness and safety using random intercept models at the participant level with fixed effects at the image level:

$$P_{ij} = \beta_1 T_i + \beta_2 I_i + U_j + E_{ij} \quad (1)$$

where: $P_{ij}$ is the perception rating on a scale of 1 to 10 to the *i*th image by the *j*th individual; $T_i$ is a dummy variable equal to one if the image contains a transport infrastructure intervention (treatment 1, 2 or 3) and 0 otherwise (control) (as presented in Fig. 1); $I_i$ is an image fixed effect for the *i*th image, included to control for each image having a different average perception rating; $U_j$ is the random intercept associated with the *j*th individual, to account for each respondent reporting their perceptions for several different images, such that these reports are not independent of one another; and $E_{ij}$ is the error term.[6] The coefficient of central interest is $\beta_1$, the Average Treatment Effect, which captures the effect of the transport intervention (treatment) on the happiness and safety levels a person associates with an image.

#### 3.4.1. Robustness check

The robustness of the results is examined by running Eq. (1) without and with control variables (Eq. (2).[7] Control variables include the eight sociodemographic characteristics of the participant, as well as three study conditions: image group, image order, and means of accessing the experiment. All figures below display estimates with the full model incorporating all controls. The model takes the following form:

$$P_{ij} = \beta_1 T_i + \beta_2 I_i + \beta 3 X_{ij} + U_j + E_{ij} \quad (2)$$

which is the same as Eq. (1), except for $X_{ij}$, which contains the demographic variables for participant *j*, and the measure of study conditions for image *i*. Only results that show a significant difference below 5% in mixed-regression models with and without controls are reported. All figures below display estimates without controls, while the full model incorporating all controls can be found in the tables in the appendices.

## 4. Results

We first examine whether a ‘standard’ BRT development – a relatively simple infrastructure of a painted bus lane and cycle lane – increases affective SWB of perceived happiness and safety when compared with a basic bus service. For this, we estimate Eq. (1) at an aggregate level. We then test whether additional gains in affective SWB can be obtained from additional improvements that go beyond standard BRT infrastructure (referred to as the ‘improved BRT’ treatments). For this, we analyze six different areas of BRT infrastructure improvements, identifying those that significantly enhance affective SWB. This involves estimating Eq. (1) on the subsamples of six areas of BRT improvements to compare standard BRT with the infrastructure options for improved BRT. Finally, we use the latter results to estimate the impacts of an ‘SWB infrastructure’-type BRT, by calculating affective SWB after incorporating only statistically significant infrastructure improvements. Regression estimates can be found in the Appendix.

### 4.1. The impact of standard BRT infrastructure on affective SWB

To compare affective SWB between the basic bus service and standard BRT, we estimate Eq. (1) on the sample of images belonging to either of these two categories (in Fig. 1, those pictures under the columns Baseline and BRT Standard). Fig. 2A displays the difference in happiness and safety perception between the two. Standard BRT (estimate[happiness]: 6.169) increases perceived happiness by just above 20.3% compared with its baseline (estimate[happiness]: 5.129). Safety perceptions also increase by 12.5% when comparing standard BRT infrastructure (estimate[safety]: 6.985) to basic bus service (estimate[safety]: 6.210).[8] Fig. 2B shows a comparison of standard BRT against basic bus services across different street contexts. For this, we modeled the standard BRT infrastructure differences from the west to east ends of Summer Street for 22 image-points[9] including a diversity of urban spaces (bridges over parking spaces and rivers, offices, industrial sites and sites under construction). Although the positive impacts of standard BRT on happiness and safety perception vary across urban contexts, they remain consistently significant across all but three Summer Street locations. Fig. 2C displays differences in affective SWB between basic bus services and standard BRT across users of different primary travel modes. Once again, we see that standard BRT significantly enhances perceived happiness and safety for users of all transport modes, including car drivers, with the highest gains reported for cyclists.[10]

[6] We report significance levels at 5% and 1%, while considering a 5% a reasonable threshold for the avoidance of Type 1 errors.

[7] We test the RCT hypothesis that, given the random assignment of control and treatment conditions, the photo-simulated scenario is the explanation for changes in perceived happiness and safety. As such, the addition of relevant observable control variables should not change the results.

[8] These percentage improvements for perceived happiness and safety are calculated by dividing beta for BRT-Standard by the constant (Basic Bus Service) and multiplying by 100, as shown in columns 1 and 3 in Table A2 in the Appendix. Full results can be found in Table A2 in the Appendix.

[9] Two bus stop improvement images - bus stop lighting and information displays- have been excluded as the basic bus service and the standard BRT pictures are the same. For full results, see Table A3 in the Appendix.

[10] See Table A4 in the Appendix.

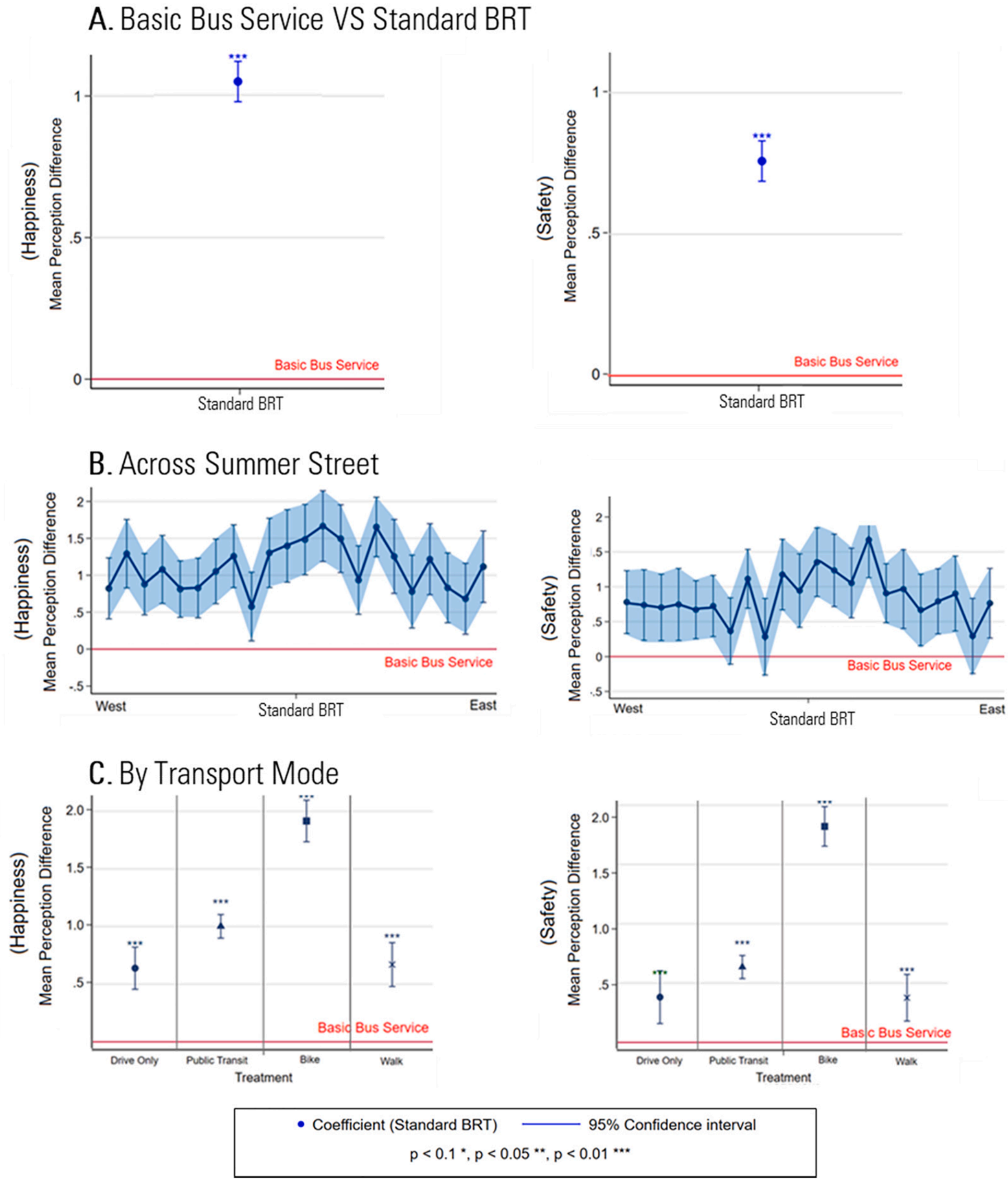


**Fig. 2.** Impact of Standard BRT Infrastructure.

### *4.2. The impact of improved BRT on affective SWB*

To test whether improvements to standard BRT generate additional gains in affective SWB, we pooled the various ‘improved BRT’ images and compared the affective SWB results against those for standard BRT infrastructure. For this analysis, we estimate Eq. (1) over the subsample of perception responses for standard and improved BRT images. Overall, these further improvements significantly increase perceptions of happiness and safety (Fig. 3A).[11] Considering once again users of different primary travel modes (Fig. 3B), we can observe positive effects of similar magnitude for both perceived happiness and safety for all except car drivers, whose safety perceptions remain unchanged.[12]

[11] Full results can be found in Table A5 in the Appendix.
[12] See Table A6 in Appendix 6.

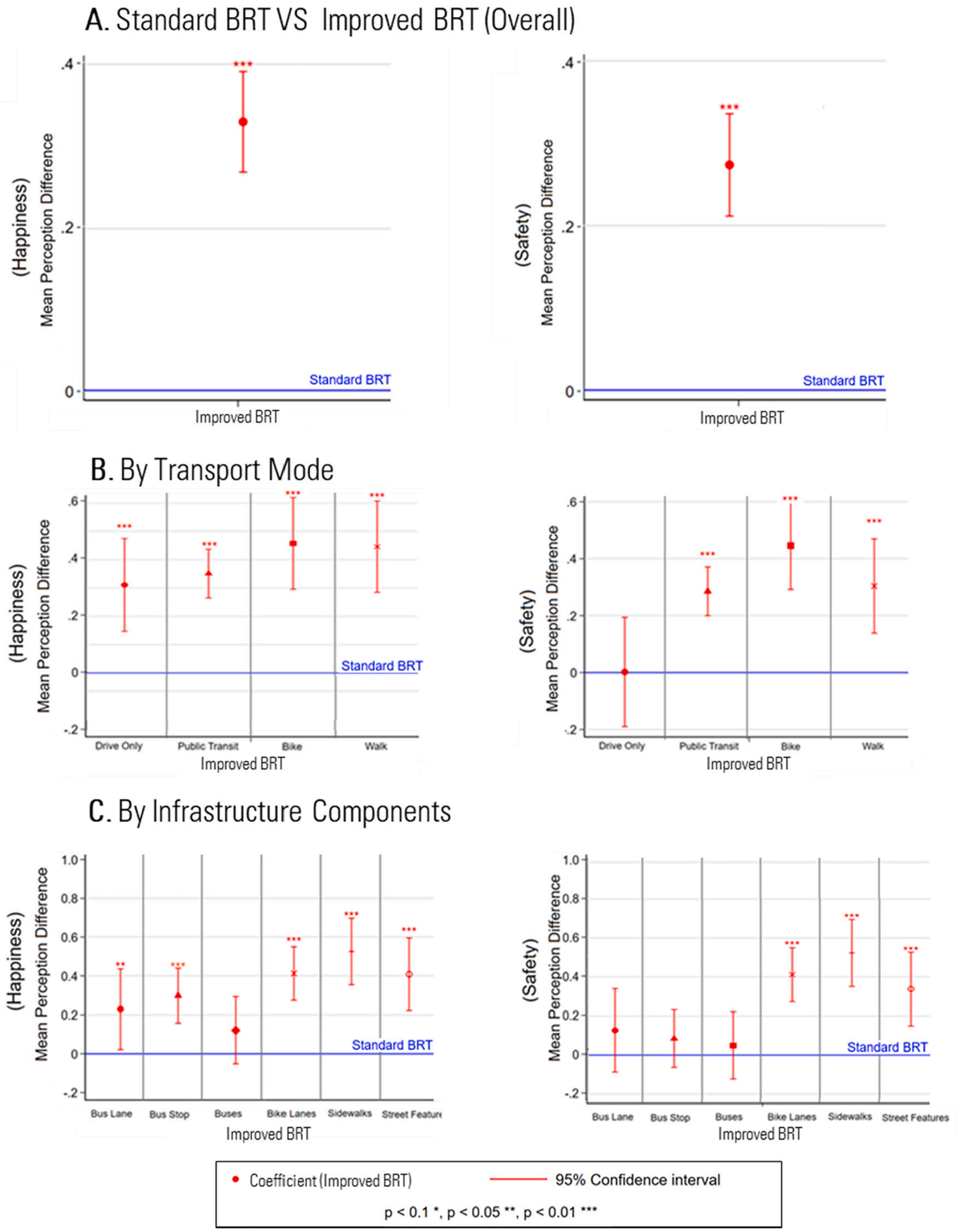


**Fig. 3.** Impact of improved BRT infrastructure.

#### 4.2.1. *Most effective areas of improved BRT infrastructure*

Fig. 3C displays the difference in affective SWB perceptions produced by six different categories of 'improved BRT' treatments when compared with standard BRT. The results show positive effects on perceived happiness and safety for those improvements that affect the walking/cycling environment – specifically cycle lanes, sidewalks, and street amenities. Improvements to bus lanes and bus stops also influence happiness, but not perceived safety.[13] This indicates that BRT investments should not only be centered on conditions for buses, but should also focus on complementary modes to further increase travelers' affective SWB.

[13] See Table A7 in the Appendix for full results.

### 4.3. What specific BRT infrastructure improvements matter for SWB?

We now turn to specific BRT features, identifying options that drive significant improvements to affective SWB.

#### 4.3.1. Core BRT infrastructure features: Bus lanes, bus stops and buses

Painted bus lanes significantly enhance commuters' perceptions of happiness, while no other bus lane configurations register significant change (Fig. 4A).[14] Regarding the different bus stop structures considered (Fig. 4B), only enhanced lighting has a significant positive impact on happiness and safety; bumpouts show a weakly significant increase in happiness. Regarding stop location, a single, centrally located bus stop decreases perceived transit safety when compared with bus stops at the curb. A center-lane bus stop, with buses traveling in both directions, has a weakly positive effect on perceived happiness. Finally, the vehicles themselves (type, power source, color) have no significant effect on happiness or safety perceptions (Fig. 4C). Overall, only a small number of bus-related infrastructure improvements increase travelers' affective SWB.

#### 4.3.2. Complementary BRT features: Bike lanes, sidewalks and amenities

Now, we examine those infrastructure features unrelated to buses. For bicycling enhancements (Fig. 5A), significant improvements to perceived happiness and safety can be achieved through: integrating cycle lanes within the sidewalk space, rather than on the road; painting the cycle lane green or blue – with no significant difference between the two colors, and; buffering the cycle lane from traffic with green space. Minimizing bus-bicycle interaction by having bicycles pass behind bus stops also significantly increases safety perceptions, while weakly enhancing perceived happiness. In contrast, mixed bus-bicycle lanes have a significant negative impact on happiness perception.[15] Regarding walking infrastructure (Fig. 5B), perceptions of happiness and safety increase with: larger and greener sidewalks; well-painted, colorful and signaled pedestrian crossings, and; the presence of terraces for restaurants and coffee shops.[16] Finally, Fig. 5C shows the impact of trade-offs among different street uses. Replacing parking spaces with a combination of cycle infrastructure and green spaces significantly increases perceptions of happiness and transit safety, while incorporating green spaces, either on one or both of a street's sidewalks, enhances happiness perception.[17] These results indicate that infrastructure improvements associated with active modes of transport can indeed have large impacts on enhancing travelers' perceptions of happiness and transit safety.

### 4.4. Setting priorities for an SWB-enhancing BRT infrastructure

In this final section, we first use the previous analysis to estimate a list detailing the effectiveness of each of the infrastructure options found to be significant in subsections 4.3.1 and 4.3.2 (these eleven options together will henceforth be referred to as 'SWB infrastructure'). Table 2 presents this list, showing for each 'SWB infrastructure' intervention the percentage of improvement for happiness and safety perception relative to the standard BRT option.[18] Following this, to evaluate these SWB infrastructure interventions as a whole, we assign participants' image ratings of BRT improvements to two groups: 'SWB infrastructure' (i.e. the eleven categories presented in Table 2) and 'No relevant improvements', representing the remaining BRT features that did not have a significant effect. For this analysis, we run Eq. (1) comparing the three sub-categories of BRT improvements (standard BRT, SWB infrastructure, and 'No relevant improvements') against the basic bus service as a baseline (see Fig. 6). [19]We first find that the SWB infrastructure increases travelers' perceived happiness by 36%, and increases safety perception by nearly 26% compared to the baseline. [20]When we compare this impact of SWB infrastructure with the impact of standard BRT, we find that the effect on happiness is 75% higher, and the effect on safety is 94% higher.[21]

## 5. Discussion & conclusion

Using a specific urban corridor – Summer Street in Boston – we present and test a novel approach using an imaged-based RCT to

[14] For full results see the Appendix. For bus lane configurations see Table A8; for bus stop designs, see Table A9; and for bus types, see Table A10.

[15] Full results in Table A11 in the Appendix.

[16] See Table A12 in the Appendix.

[17] Estimates in Table A13 in the Appendix.

[18] These estimated percentage improvements for perceived happiness and safety are calculated by dividing significant beta estimates (BRT improvement features) by the constant (standard BRT) and multiplying by 100, as shown in Tables A8 to A13 in the Appendix.

[19] Fig. 6 reports OLS regression results of deviation of happiness or sadness perception on a categorical treatment variable. In all panels, the treatment categorical variable is equal to 0 for control images (Basic Bus Service), 1 for treatment 1 (Standard BRT), 2 for treatment 2 (SWB Infrastructure), and 3 for treatment 3 (No relevant improvements [not shown]). Full results in Table A14 in the Appendix.

[20] These estimated percentage improvements for perceived happiness and safety are calculated by dividing the beta for SWB infrastructure by the constant (Basic Bus Service) and multiplying by 100, as shown in columns 1 and 3 in Table A14 in the Appendix. We consider this a reasonably conservative estimate, as it presents the mean impact of combined improvements, rather than considering that the improvements together may have interacting positive effects. For example, it is reasonable to consider that combining a larger sidewalk with a green-buffer cycle lane would be at least as effective at increasing affective SWB as the most effective of the two.

[21] These estimated percentage improvements for perceived happiness and safety are calculated by dividing the beta for standard BRT by the beta of the SWB infrastructure and multiplying by 100, as shown in columns 1 and 3 in Table A14 in the Appendix.

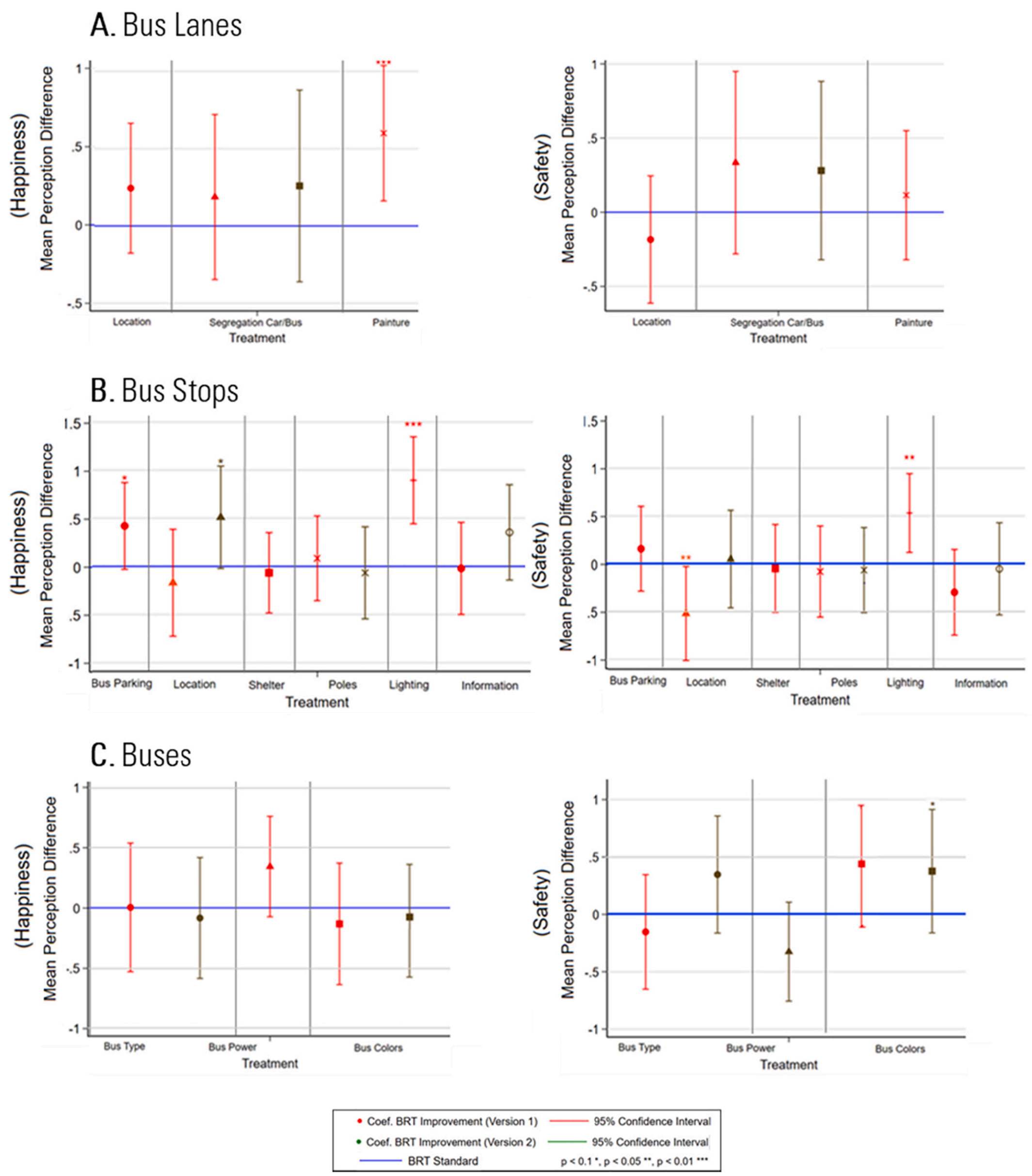


**Fig. 4.** Impact of core components of BRT infrastructure: bus lanes, bus stops and buses.

provide causal evidence of the relationship between changes to BRT infrastructure and travelers' affective SWB. The results demonstrate that BRT infrastructure has a positive impact on individuals' perceptions of happiness and safety, regardless of these individuals' regular transport mode. We also find that further improvements – most notably infrastructure improvements to cycle lanes, sidewalks and street features – lead to additional increases in travelers' affective SWB.

This study expands the scope of the SWB-mobility literature, which has typically concentrated on the impact of commuting, transport modes, and personality traits on SWB, but has largely ignored the influence of bus infrastructure on the traveler experience (Chatterjee et al., 2020; Norgate, 2020; Ieda and Muraki, 1999; Spinney et al., 2009; Mollenkopf et al., 2011). We also build on the literature around SWB and the built environment, moving beyond its current scope examining the impact of green spaces and residential environments on SWB (Van den Berg et al., 2010, 2014; Navarrete-Hernandez and Laffan, 2019; Cao, 2016; Helliwell and Putnam, 2004; Schwanen and Wang, 2014) to analyze the consequences of transport-related transformations of the built environment beyond cycle lanes.

This study has several implications for policy and practice. Individuals exposed to a standard BRT infrastructure experience higher levels of perceived happiness and safety compared to a basic bus service; this effect remains consistent across different street contexts and for those using different transport modes. This implies that "light" infrastructure solutions (e.g. painted bus and cycle lanes) not only provide an inexpensive and quick way to implement exclusive bus lanes, but also improve all travelers' affective SWB. Notably,

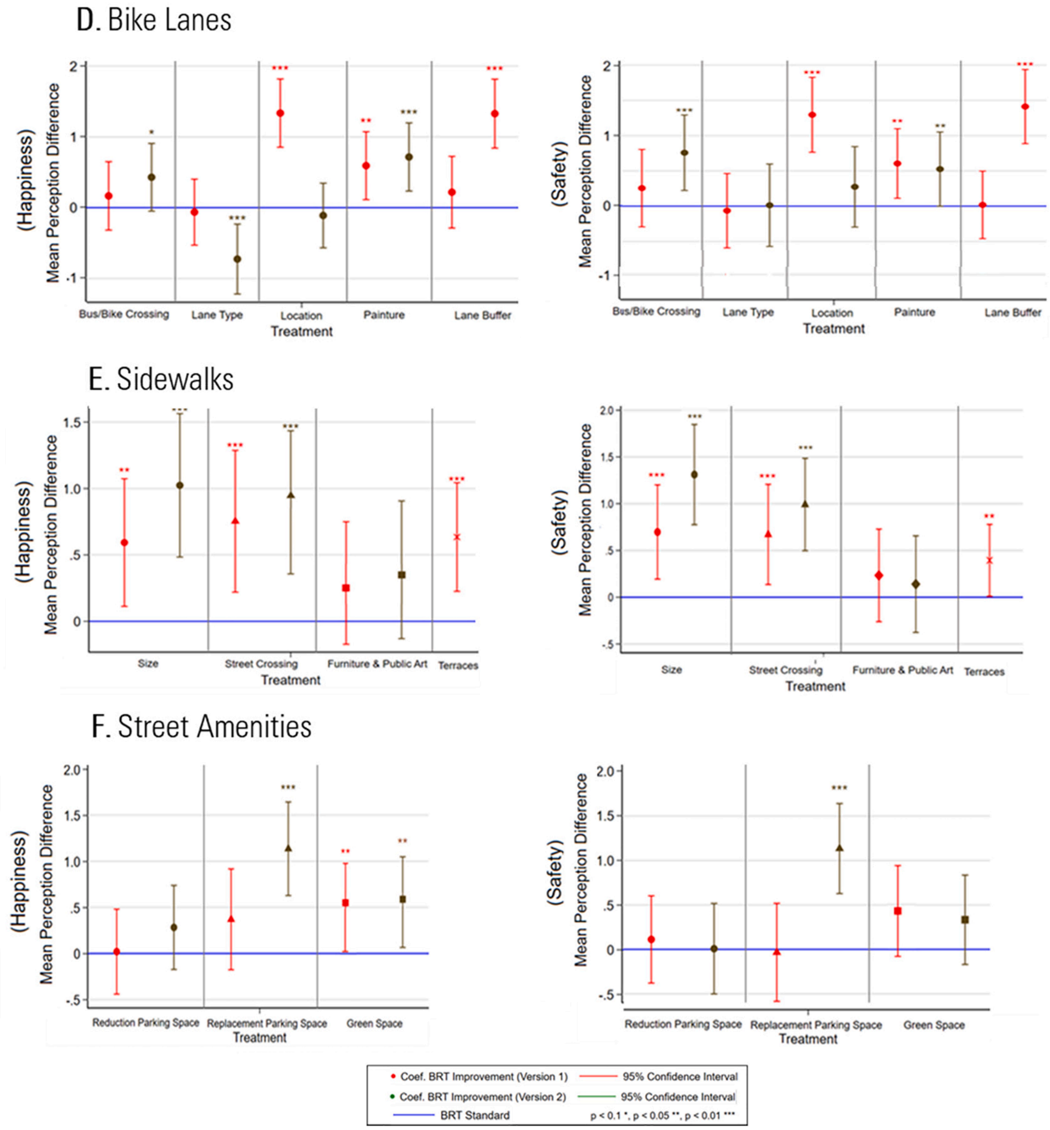


**Fig. 5.** Impact of complementary components of BRT infrastructure: bike lanes, sidewalks and street features.

**Table 2**
Percentage of improvement of relevant BRT interventions.

| N | Type | % Happiness | % Safety | Average[1] |
|---|---|---|---|---|
| 1 | Large Green Sidewalk | 21% | 26% | 23.65% |
| 2 | Sidewalk-Cycle Lane | 22% | 23% | 22.52% |
| 3 | Bus Stop Lighting | 30% | 14% | 22.07% |
| 4 | Cycle Lane Green Buffer | 23% | 21% | 21.88% |
| 5 | Replacing Parking with Cycle-Green Space | 19% | 14% | 16.63% |
| 6 | Painted Street Crossing | 15% | 15% | 14.88% |
| 7 | Painted Cycle Lane | 9% | 8% | 8.83% |
| 8 | Terraces | 8% | 5% | 6.40% |
| 9 | Bus-bicycle Crossing | 0% | 11% | 5.33% |
| 10 | Painted Bus Lane | 10% | 0% | 5.00% |
| 11 | Green Spaces | 9% | 0% | 4.61% |

Note 1: This result reports the average improvements of perceived happiness and safety as an indicative statistic. However, there is intense debate about the relative importance of different emotions. This indicator should therefore not be considered as giving a prioritized list of improvements, as assigning different weightings would alter the order of the list.

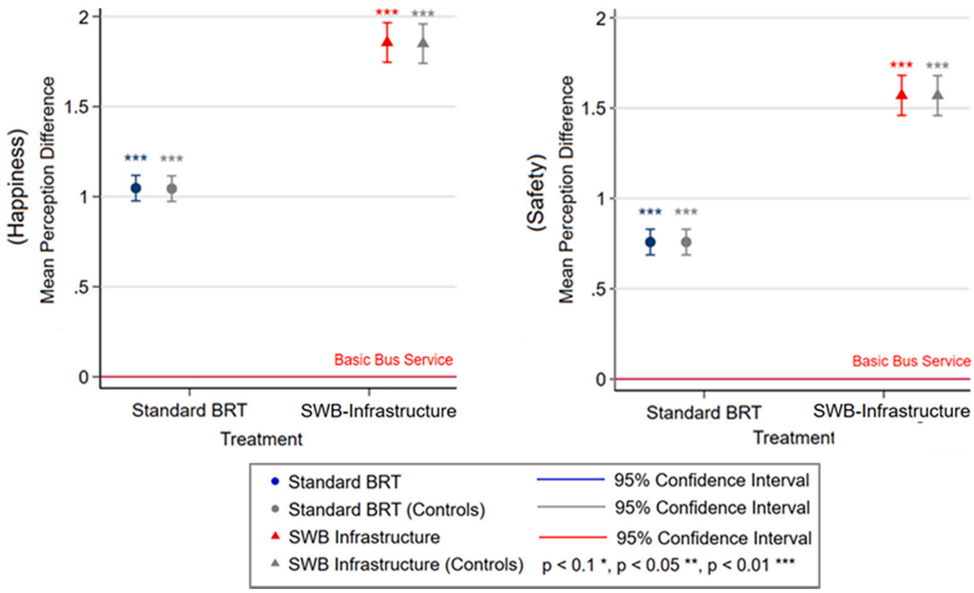


**Fig. 6.** Impact of SWB-Infrastructure on affective subjective well-being.

this includes car drivers, arguably the users most likely to be negatively impacted by BRT solutions which might replace parking spaces and private vehicle lanes with exclusive bus lanes. This may help transport planners in overcoming the community opposition challenges to implementing BRT enhancements. Moreover, the fact that, relative to standard BRT infrastructure, further BRT design improvements significantly increase happiness and safety perceptions (again, for users of all transport modes) implies that BRT design is important for travelers beyond the traditional travel-time savings benefits. This finding could help planners rebalance objective and subjective well-being considerations when assessing the value of BRT infrastructure alternatives (Rodriguez and Mojica 2009; Munoz-Raskin, 2010).

Regarding infrastructure policy recommendations, aside from painted exclusive bus lanes and a well-lit bus stop, further investments in bus-related infrastructure do not yield substantial gains for travelers' perceived happiness and safety. Instead, more transformative SWB outcomes come from complementary infrastructure for active modes of transport and from street amenities. Our results further reveal that, of the 65 infrastructure options commonly implemented as BRT improvements, only a few have significant effects on affective SWB. This brings into question the capacity of expert-based strategies as the sole method informing BRT design guidelines; understanding affective SWB responses, among the broad members of the community, can and should play a role.

Towards that end, our image-based method identifies eleven improvements with significant effects, enabling us to offer the first set of evidence-based BRT infrastructure recommendations for increasing affective SWB in Boston (Table 3). Among these changes, common factors include painting transit lanes – whether this means bus lanes, cycle lanes or street crossings – and the incorporation of green spaces, such as green buffers for cycle lanes, green sidewalks and tree-lined streets. The importance of greenery is not entirely surprising, as it aligns with several studies from environmental psychology, which indicate that increased vegetation yields increases in positive emotions, including happiness (Kim et al., 2010; MacKerron and Mourato, 2013; Pfeiffer and Cloutier, 2016). Furthermore, emerging studies indicate that the presence of greenery might also affect perceptions of safety (Jiang et al., 2017; Navarrete-Hernandez and Laffan, 2019). Regarding the impact of painted lanes, the evidence is less compelling; a few studies report that more diverse street color landscapes can enhance positive emotions (Gu et al., 2021; Zang et al., 2021), and that painted cycle lanes and sidewalks increase travelers' perceived safety, perhaps making users feel more visible to other vehicles (Gössling and McRae, 2022). Clearly, the most effective and affordable means of enhancing SWB through BRT infrastructure requires a shift from a bus-centered to a mobility-centered approach, allowing for positive impacts on all travelers, regardless of their choice of transport mode. Future BRT infrastructure projects should aim to incorporate these relatively affordable and effective design features whenever possible.

Despite our contributions, many caveats still apply to this study, opening avenues for further research. Regarding the means of measuring affective SWB, we focused on two key measurements – feeling happy and safe – from a potentially much larger universe of positive and negative feelings. Debate continues, for example, about whether SWB measures should be aggregated or considered separately (Stone and Mackie, 2013). Further studies could use a combination of affective SWB scales, such as SCAS or SPANE, to understand the extent to which these different psychometric scales capture similar or complementary measurements when applied to travel research (Singleton, 2019). Our study sets an important baseline from which future studies can expand to consider other relevant emotions, for example anger and sadness, when assessing the impact of BRT infrastructure.

Another limitation in our work is our use of an image-based RCT that relies on static visual stimuli. Compared with video and virtual reality, photo-simulation provides a less immersive visual environment, thus resulting in a less true-to-life representation of the wider context that might impact affective SWB. Our static images ignore the auditory landscape, motion, and other relevant environmental and social considerations. Future studies using the same strategy in a virtual reality setting could partly overcome these

**Table 3**
BRT infrastructure recommendations for improving perceptions of happiness and safety.

| Before BRT Treatments | After BRT Treatments |
|---|---|
|  |  |

| Infrastructure Type | Intervention Type | Treatments | BRT Infrastructure recommendations |
|---|---|---|---|
| Bus related | Bus Lanes<br>Bus Stops | Painted<br>Lighting | Bus-related infrastructure should include painted bus-lanes and well-lit bus stops. |
| Bike related | Bike Lanes | Bus Bike Crossing<br>Location<br>Painted<br>Lane Buffer | Bike-related infrastructure should consider painted bike lanes placed on sidewalks separated from the road with a green space buffer. Bike lanes should pass behind bus-stops whenever is possible. |
| Pedestrian related | Sidewalks | Size<br>Street Crossing<br>Terraces | Pedestrian-related infrastructure should focus on wide sidewalks with the inclusion of bar/restaurant terraces whenever possible. Pedestrian street crossings should be colorful and well-signaled. |
| Street design related | Street amenities | Replacement<br>Parking Space<br>Green Space | Regarding street distibution, parking lots should be replaced by bike lanes and green spaces. Additionally, BRT corridors should be tree lined streets on both sides. |

limitations, although this might come at the expense of a smaller and less diverse sample. Despite their limitations, photo-simulations have two important benefits. First, compared with more immersive technologies, they provide a low-cost strategy to simulate BRT infrastructure, making the method accessible for practitioners in cities across the world. Second, this approach arguably provides a conservative, lower-bound estimate of SWB, as aligned stimuli presented in more immersive technologies would typically result in impacts in the same direction but of stronger magnitude (Rossetti and Hurtubia, 2020).

Although our results have strong internal validity, they cannot be generalized, as preferences might be culturally constructed and thus may change across cities and countries. Applying the same or a similar experiment across different contexts would help to overcome this problem and allow us to test the universality of our results.

As a final potential expansion of this work, the image-based RCTs developed and used for this study can be further utilized to consider the impact of other transport infrastructure types – such as sidewalks, or highways – on SWB. Furthermore, by running similar experiments with local communities, practitioners can create transport infrastructure that not only takes into account impacts on affective SWB, but also addresses geographical specificities, such as urban contexts, cultures or the preferences of local travelers. By placing affective SWB as a central consideration for transport infrastructure, planners can indeed work towards maximizing the SWB of communities in cities across the world.

## CRediT authorship contribution statement

**Pablo Navarrete-Hernandez:** Conceptualization, Project administration, Methodology, Formal analysis, Data curation, Visualization, Writing – original draft, Writing – review & editing. **P. Christopher Zegras:** Conceptualization, Project administration, Formal analysis, Writing – original draft, Writing – review & editing.

## Declaration of Competing Interest

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

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tra.2023.103670.

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