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An evaluation of the impact of COVID-19 safety measures in public transit spaces on riders' Worry of virus contraction

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ABSTRACT

The coronavirus pandemic has brought about global change in travel behavior. Transit ridership volumes have dropped to record lows. Concerning environmental, health, and social consequences lie in store if transit networks are not able to regain a substantial portion of pre-pandemic users. Transit providers have implemented several interventions aimed at both slowing the spread of the virus and retaining riders as travel restrictions lift. While the effectiveness of these measures has been evaluated with respect to spread rate reduction, little consideration has been given to their impact on riders' feelings of worry regarding virus contraction. By deploying a photo-simulation approach in a randomized control trial, this study finds that level of compliance with safety measures and the conditions of transit spaces themselves significantly impact riders' levels of worry. Given these findings, a series of recommendations are made regarding compliance practices that are expected to lessen rider worry regarding the risks of COVID-19 infection.

1. Introduction

COVID-19 has significantly altered transportation-related behavior. We have seen impacts on *the ways* people make trips, *the places to which* they make them, and *the frequency* with which they are made (Hunter et al., 2021). With over half of the world's population being asked to stay at home or restrict their movement in public during 2020 (Sandford, 2020), public transit systems have seen their ridership levels drop to unprecedented levels. During the first several months of the pandemic, with travel widely restricted to all but essential workers, it was not uncommon for transit networks to see ridership drop by as much as 85 to 95 percent compared to the same months in 2019 (Community Mobility Reports, 2021). For example, ridership fell 87% in Bogotá (Sanchez, 2020), 89% in Delhi (Aloi et al., 2021), 88% in both Milan and Madrid (Global Public Transport Report 2020), 85% in Singapore (Mahtani et al., 2020), and 90% in both London and New York City (ibid.). As mobility restrictions were broadly relaxed towards the end of 2020 and into the start of 2021, some transport systems saw recovery of 40–50 percent of their 2019 ridership levels (Muoio, 2020; Wilbur et al., 2020; Qi et al., 2021). Unfortunately, global recovery trends were, on average, below this range (Ritchie et al., 2022).

The coronavirus pandemic went on to alter the very nature of work, school, and play – how, when, and where we do them – and the ways we use public transit systems to facilitate trips of those purposes. As such, it is uncertain if transit systems will fully recovery to pre-pandemic ridership rates, even in a potential post-COVID future (Bagdatli and Ipek, 2022; de la Garza, 2020). This naturally raises the question: *What are the implications for the world of transit if these trends continue to persist?* Transit practitioners have suggested that persistent drops in ridership could lock us into a concerning downward spiral in which ridership falls, revenue drops as a result, service provision decreases due to diminished operating budgets, and ridership in turn falls further (Sadik-Khan and Solomonow, 2020; Verma, 2020). With many of the world's largest transit providers reporting weekly losses in the high tens of millions of US dollars (DiNapoli, 2021; Nugent, 2021; Burroughs, 2020), and systems from Paris and Washington, D.C (Mahtani et al., 2020). to Ulaanbaatar (Null and Smith, 2020), Addis Ababa (Abubaker, 2020), and Johannesburg (Nkosi, 2020) operating with service levels at 50% capacity or less, the patterns exhibited toward the end of 2020 and on into 2021 (Bliss, 2021) suggest that this cycle has already begun.

The pattern of *decreased ridership, decreased revenue, decreased service, repeat* also has major implications for transit equity. Essential workers

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and socially vulnerable communities (e.g. the elderly, low-income earners, racial minorities, women) make up a disproportionately large share of the during-pandemic global transit ridership body (George et al., 2021; Bliss, 2021; Morales-Burnett and Freemark, 2021; He et al., 2022; Asian Development Bank, 2020). Because these riders continue to depend on transit to meet their travel needs, the burdens associated with service cuts – burdens such as lengthened waiting times, decreased or discontinued early morning and late night service, dropped transfer/connection opportunities, increase total trip times – are largely being shouldered by these communities. This lowering of transit trip quality contributes negatively to existing states of transportation equity across these socio-demographic lines as those with means and alternative options increasing exercise the privilege of being able to work remotely or of selecting a different mode that offers a less compromised travel experience.

The concerning effects of transit's spiraling trajectory do not stop there. Thus far over the course of the pandemic, the environmental narrative has been largely positive. Travel restrictions and decreases in production seen around the world have contributed to improvements in air and water quality in particular (Isaifan, 2020; Anjum, 2020; McGrath, 2020; Saadat et al., 2020). Additionally, there has been significant growth in the adoption of sustainable modes of transport – e.g. bicycles and e-scooters – which has further contributed to decreased emissions (Hu et al., 2021). However, studies have explored people's intended means of transport as restrictions lift and needs change, and have found travel by car to be the dominant substitute mode-choice for travelers whose primary pre-pandemic mode was public transport (Pryzbylowski et al., 2021; Thomas et al., 2021). If this mode shift toward private cars persists and the downward cycle of transit is not reversed, these recent positive environmental outcomes could be undone (Andersen et al., 2021), and there is a risk that a significant part of the progress made towards sustainability goals of cities around the world may be undermined (De Gruyter et al., 2016; United Nations, 2020).

Well-aware of these circumstances and committed to regaining stable footing, transit agencies have implemented a host of interventions that focus on virus spread-risk reduction and rider comfort to incentivize continued and returning ridership. These have included temperature checks at bus stops, portable self-cleaning stations at system access points (Economic Times, 2020), limited on-board passenger capacity (Schwartz, 2020), increased frequency of vehicle cleaning and improved ventilation (ibid.), contactless payment/ticketing options and rear-door-only circulation offerings to minimize contact with vehicle operators (Null and Smith, 2020).

Of the many COVID-19 safety measures (CSMs) implemented in transit spaces, the most widely adopted have been the introduction of mandatory face masks, floor and seat markers defining physical distancing, and the provision of hand sanitizing materials (Null and Smith, 2020). Due to the low cost, ease of implementation, and high multi-modal versatility of these measures, they were adopted in comparatively early stages of the pandemic, and have become commonplace globally. These measures have been evaluated with respect to their impact on rates of virus spread and have ultimately been deemed effective (Fazio et al., 2021; Milne and Xie, 2020). For example, research has found that COVID-19 spreads 10 to 35 times faster in the absence of social distancing (Courtemanche et al., 2020). Further research has demonstrated that the extent to which these interventions have reduced the risk of spread is dependent on the combination of measures in place and levels of adherence (Thu et al., 2020). However, while we now understand the epidemiological efficacy of these measures, their impacts on the emotions of transit users remains much less widely studied.

From the wide range of possible emotional responses that could be considered, the feeling of worry was selected as the focus of this research as it plays a critical role in an individual's transportation mode choice. Mode choice is impacted by many factors, from socio-demographics (Ouali et al., 2020; Lubitow et al., 2020) and the built environment (Cervero, 2002), to attitudes toward travel (Stewart et al., 2012; Lanzini and Khan, 2017) and personal health conditions (Schmöcker et al., 2008). However perception of risk has been cited as one of the most pertinent and influential of these factors (Muley et al., 2020; Delbosc and Currie, 2012; Ceccato et al., 2021; Ozbilen et al., 2021). The perception of risk is, in turn, intimately linked with feelings of worry: several studies have shown that worry is the most important contributor to the ways in which we interpret and assess risk (Moen and Rundmo, 2006; Khosravi, 2020; Dryhurst et al., 2020). Additionally, feelings of worry have been found to be consistently induced during epidemics and public health crises (Hansen, 2009; Jalloh et al., 2018; Klemm et al., 2016). Studies specific to the COVID-19 pandemic have similarly found this to be true (Serafini et al., 2020; Klos-Adamkiewicz and Gutowski, 2022). Worry is also directly related with not only short-term but also long-lasting behavioral changes (Lee, 2020). Taken together, these factors demonstrate that feelings of worry stand as a central element in influencing transit ridership trends.

A mobility behavior case study of Gdansk, Poland explores this relationship between worry and transit ridership in the context of COVID-19 acutely. During the mid-summer of 2020, via random sample survey, the research team of Przybylowski et al. (2021) asked transit riders about their travel choices as well as their feeling of "safety and comfort" while using transit. They found that about 90% of respondents fully resigned (47%) or limited (44%) their usage. This is not surprising, given the early stage of the pandemic in which this study was conducted, and aligns in magnitude with the global trends discussed earlier in this section. When asked about the reasons for their decreased transit use, the most common answer (49% of respondents) involved a switching of work and/or schooling from an in-person model to a remote one. The second most commonly cited reason (40% of respondents) was a fear of coronavirus infection. Interestingly, 75% of this respondent cohort stated that they planned to return to their pre-pandemic levels of usage "when the epidemic situation has stabilized." The other 25% had "lost hope" that transit will ever be COVID-safe. This study speaks directly to the relationship between perceived safety, fear, and concern and transit ridership.

It is against this backdrop that this research is positioned. By using a photo-simulation approach in a randomized control trial, the following question is explored: How do CSMs in transit spaces affect travelers' worry of COVID-19 infection, and how do the conditions of transit spaces themselves influence this effect? For transit planners and policy makers, this work offers insight into the effectiveness of widely adopted CSMs in mitigating riders' concerns. Such knowledge could help providers fine-tune their interventions, better direct their resources, and, most pressingly, quicken the rate at which riders return to their systems. While some urban populations are transitioning towards herd immunity, an examination of this intersection of COVID-19, safety interventions, and transit ridership remains relevant, particularly in geographical contexts where vaccination rollout is limited or where new variants of the coronavirus are spreading.

This paper is structured in the following way. Section 2 highlights the primary findings from relevant literature on the perceived risk of COVID-19 infection. Section 3 lays out the randomized control trial methodology of the study including details of participant sampling, data collection methodology, and data analysis. Section 4 presents the results and reflects on the limitations of the research. Section 5 concludes with a discussion of the policy implications, and identifies opportunities for future research.

2. Literature review

This study is situated within a new and growing line of research whose objective is to better understand the psychological underpinnings of mobility behavior during the COVID-19 pandemic. The past two years have seen the publication of a number of such studies, with their

primary focus being perceptions of risk of COVID-19 infection in varied transportation settings.

In the very early stages of the pandemic, the team of Ozbilen et al. (2021) looked at perceptions of risk of infection associated with different travel modes in Columbus, Ohio. This study entailed an online survey that ran from April to May of the pandemic's first year. It explored how stated levels of perceived risk, measured by a five-point Likert scale, were impacted by factors of age, gender, level of education, employment status, and household income. Among the socio-demographic characteristics tested, age and income levels proved to have a significant impact, with decreasing levels of perceived risk for increased age and higher incomes. The authors hypothesized that income-related findings were a function of access to better health insurance. Rather unsurprisingly, across all socio-demographic classification, perceived risk was significantly higher for shared transportation modes than for private modes, with transit – in this case only buses – rendering the highest perceived risk of all.

Further into the first year of the pandemic, Zafri et al. (2022) deployed a similar method – using an online survey and Likert scale measurements – exploring risk perception across mobility modes in Bangladesh in July and August of 2020. Their findings aligned with those of Ozbilen et al. (2021) with respect to the effects of age and income on perceived risk. However, they found that gender also had a significant impact with women perceiving greater levels of risk across all modes studied. Additionally, Zafri et al. (2022) expanded on previous work by including questions about how feasible respondents felt it was to achieve COVID-19 safety recommended behavior in public transit environments. Among the 804 respondents, 75% disagreed or strongly disagreed with the statement 'Social/physical distancing is possible in public transport', with only 16% of respondents agreeing with this statement to any degree.

Research from Turin, Italy by Gnerre et al. (2022) continued this line of inquiry. Engaging online survey participants between January and March of 2021, this work focused specifically on perception of risk associated with transit. It expanded on past efforts by combining an exploration of risk perception of COVID-19 infection with stated satisfaction levels, and comparing these stated risk and satisfaction levels across three different time period: pre-pandemic, the present, and a projected post-emergency phase of the pandemic. The results showed the perceived risk of COVID-19 to be higher in transit vehicles than in waiting areas, and that this perceived risk existed not only at that present moment, but also for the riders' projected non-emergency future scenario. This line of questioning introduced to the literature evidence of the need to assess the potentially lasting, persistent nature of COVID-induced effects on transit use.

Expanding on these studies further, Parady et al. (2020) assessed how the impacts of COVID-19 on travel behavior differed by trip purpose. Focusing on the Tokyo metropolitan area during the first year of the pandemic, this research looked at perceived risk in the form of COVID-19 'dread', finding that dread motivated a "non-negligible increase" in probability to decrease travel overall, irrespective of mode. The authors articulated that, with fewer necessary activities – for example grocery shopping, work, and schooling – requiring travel outside of the home, transit rider return may have an increased dependence on choice trips. Maximizing ridership therefore necessarily depends on encouraging the making of non-essential trips. Parady et al.'s (2020) findings suggest that, at least in part, that requires efforts in minimizing dread.

The experiment conducted as a part of this research draws from and expands upon the literature presented above in several ways. First, this research follows the established methodology of testing the impact of age and gender. These two socio-demographic factors were most consistently found to have a significant impact on perceptions of risk of COVID-19 in transportation settings. On a second point of similarity, this research uses a Likert scale as the measurement technique for its variable of interest. However, this study differs from existing literature in that it is the first to test variation in COVID-related worry across different transit modes and spaces, to test the impact of CSMs and compliance levels, to introduce a randomized control trial methodology, and to incorporate the use of visuals (photo-simulated images).

With the aim of providing the first evaluation of the effectiveness of CSM policy in impacting riders' feelings, this research builds upon the groundwork laid by earlier studies. As recommended by Gnerre et al. (2022), this study tests whether an increase in information provision might impact rider feelings. As recommended by Zafri et al. (2022), the potential influence of discrepancies in COVID-19 immunity between individuals is examined. Finally, this study takes place in a cross-geographical context, incorporating recommendations made by Parady et al. (2020) to consider multiple cities within a single experiment.

3. Methodology

3.1. Conceptual model

This research set out to assess how different CSMs affect people's worry in public transit spaces. To attain this objective, the widely deployed CSM interventions of required face mask use, physical distancing, risk reduction behavior information dissemination, and hand sanitizer dispenser provision were simulated. These CSMs were positioned across different transit modes and within different physical spaces that one is likely to encounter while traveling via transit. These spaces were modified to reflect varied CSM combinations and levels of compliance with restrictions. Worry of COVID-19 infection was then measured using the psychometric scale developed by Taylor et al. (2020) to determine perceived risk of potential infection.

The specific interventions of face mask use, physical distancing, hand sanitizer dispenser provision, and information dissemination were chosen for simulation as they have each formed a central part of the landscape of COVID-19 safety measures undertaken worldwide, particularly in dense urban areas (Null and Smith, 2020). Face mask requirements and physical distancing markers in particularly were widely implemented (ibid.). While studies suggest that compliance with hand sanitization measures may in fact be low (Guellich, 2021; Nguyen and Pojani, 2021), it was nevertheless hypothesized here that the presence of dispensers might play an important psychological role in reducing worry of COVID-19 infection because of their high visibility and the sense of hygiene control they offer to users in an otherwise highly uncontrollable situation (Moen and Rundmo, 2006). For example, while a rider may not be able to choose how often the hand railing on a bus gets cleaned, they can choose to sanitize their own hands before, during, and/or after they ride the bus. Regarding the provision of information, several randomized controlled trial studies indicate that an increase in information presented to the public can be a powerful and cost-effective strategy to change perceptions and behavior around an issue (Andersen et al., 1998; Blamey et al., 1995; Bursztyn et al., 2020), including risk expectations (Shrestha, 2020). It is for these reasons that these CSM were centered within this work.

Participation in this randomized control trial was carried out in three stages. Stage 1: all participants signed an online consent form and completed a questionnaire on socio-economic characteristics, travel patterns, and self-assessed COVID-19 vulnerability. Stage 2: participants were randomly assigned to one of three conditions. Under one condition, participants were presented information indicating that hand sanitizer was provided in all metro and train stations and at bus stops. Under the second condition, information was provided on the reduction in risk of transmission achieved by social distancing of 1 m or more and face mask use. The third condition offered neither hand sanitizer nor risk reduction information. Stage 3: participants rated 19 (out of a potential 76) randomly assigned photo-simulated scenarios. These scenarios featured different levels of compliance with CSM guidelines across four modes of public transport (metro, train, tram, and bus), plus one image of an

empty park that all participants rated. For each photo-simulated scenario, participants rated their worry of COVID-19 infection in the presented space on a ten-point scale: from 'not at all' to 'extremely worried' about contracting COVID-19.

Four different scenarios were simulated: 1) empty transit spaces, which served as the baseline worry of COVID-19 infection in each space; 2) a no-CSM compliance scenario, in which no people in the simulated image were physically distancing or wearing face masks; 3) partial CSM compliance, in which some people in the image adhere to the physical distance markers, and some wear face masks, with some masks not appropriately covering both nose and mouth; and 4) full CSM compliance, in which all people comply with physical distance markers and wear face masks correctly. These four scenarios were simulated across nineteen common typologies of public transport spaces (e.g. connection hall, ticket office, stairs, platforms, seating areas, inside coaches) encapsulating the diversity of spaces that a transit user may engage with while traveling (see Image 1 for examples and Image 2.A in the Supplementary Material section for the full set of images used).

Additionally, an empty, daylit public park – with no people and no seating area – was included. This served as a baseline of minimum worry of COVID-19 infection in a public space, against which worry in transit spaces and the impact of CSMs were compared. An empty park was selected as a baseline for two reasons. First, virus contraction has been directly linked to the presence of other people, the presence of frequently touched surfaces, and a lack of ventilation; therefore it seems reasonable to present the public park – a well-ventilated outdoor area, with no people and no objects such as public bins or seats – as a public space that, while both familiar and regularly frequented, is able to provide the lowest possible opportunity for contracting COVID-19.

Second, this choice was motivated by the very nature of what it means for a space to be *public,* and the implications that that has for levels of personal *control* over a space. At least in concept, all have access to a public space, and a public body is charged with the authority to make changes in, assign rules and regulations over, and to enforce said regulations within that space. This is true in both the case of the park and most transit spaces. In both cases, one's worry is, at least in part, derived from not knowing who used the space previously nor who you may end up sharing the space with, and having no real power over the behavior of others within that space. Given these two points, worry of infection in the public park provides a convenient means of understanding the minimum possible achievable worry of infection in a potentially shared space open to the public.

Along similar lines, this was deemed a more useful comparison for policy makers than, for example, a comparison to worry felt while using a private vehicular mode. In the private vehicle case, the vehicle operator would have much more control (e.g. able to make decisions about who else enters the car) and therefore much more direct influence over the COVID-related riskiness of a given situation. Given how important a contributing factor to worry perceived control is (Moen and Rundmo, 2006), we argue the low control environment of the park makes for a better COVID-riskiness comparative with the low control transit scenarios.

3.2. Sampling method

Participant recruitment was conducted online through paid social media advertisements restricted to people over 18 years of age and located in London (United Kingdom), Milan (Italy), and Santiago (Chile), with the results gathered between November 10th, 2020 and January 10th, 2021. This online method of data collection facilitated access to participants across the three cities, and social media advertising allowed for a wide reach, exposing recruitment offers to a sizeable sample of participants.

The three major cities selected as focal sites all have major transit networks including train, metro, and bus options. Milan additionally has a comprehensive tram network. In all cities, face masks were compulsory, and physical distancing was encouraged. In Milan and London, hand sanitizer dispensers were available at all train and metro stations, while in Santiago these were not widely provided. These cities also offer contrasts in their contexts of geography, public health, and transit use. Cities from both hemispheres were intentionally selected as seasonality has been found to impact the number of active COVID-19 cases (Liu et al., 2021). At the time of data collection, Milan and London were entering their 'second wave' winter peak of COVID-19 infections with London reaching just over 35,000 daily cases and Milan just over 20,000 cases/day, while during most of this period Santiago was recording a low number of infections; just shy of 1500 cases/day during the southern hemisphere summer. COVID-related death trends also differed during this period: the UK experienced an upward trend, reaching 800 deaths per day at the end of data collection, while in Italy this trend was reversed, decreasing from over 700 deaths per day to fewer than 500. In contrast, Chile maintained a comparatively flat rate, remaining below 50 deaths per day.

As the UK and Italy entered their second waves of COVID-19 infections, tight mobility and lockdown restrictions were present during most of the data collection period in both cities. In contrast, only light mobility restrictions were imposed in Santiago, with no lockdowns occurring throughout the data collection period. Regarding impact on public transport use, the three cities experienced a significant loss of public transport riders in 2020 all maintaining monthly average ridership volumes below 50% of the corresponding months from 2019, and large numbers of commuters reported using public transport less often than they had previously (London: 39.2%; Santiago: 44.8%; Milan: 42.2%) (Global Public Transport Report 2020). A global app-based survey of commuters conducted by Moovit, found that measures to increase social distancing throughout the transit travel experience were the most important factors in returning to public transport for commuters in both Milan and Santiago. London-based commuters ranked this CSM as the second most important influencer over their potential return to transit behind increasing vehicle frequency to reduce onboard crowding (ibid.).

A total of 564 people participated in this study: 49.3% of participants were from Milan, 40.3% from Santiago, and 5.8% from London. An additional 4.5% of respondents are from other cities in the world, as the link might have been reshared on social media. This participant cohort produced 11,283 image ratings, with an average time of 5 min and 37 s taken to complete the experiment. No payments were offered to participants. Participants accessed the experiment through a link on their device (desktop, tablet, or mobile phone) and were prompted to read the study protocol, and all participants signed an online informed consent form prior to being sorted into a treatment group, and finally rating their randomly assigned photo-simulated scenarios.

A specialized research platform (www.urban-experiment.com) was used to run this image-based experiment. The platform maximized full-screen display of images on any device used. To ensure participants were balanced across CSM scenarios, a double randomization process for the images was introduced. First, the research platform randomly allocated the order of appearance of the 20 categories of spaces presented to each participant. With this, the order of all the presented images was balanced, thus minimizing the impact of potential participant attention or fatigue effects. Second, as is customary in randomized controlled trials, only one image was randomly selected and rated by participants for each category of image. This double randomization process allowed for, in a single experiment, the conducting of multiple control trials testing CSMs across several transit scenarios, maximizing data collection while eliminating potential confounders.

3.3. Data collection

Data pertaining to three categories was collected: 1) participants' background characteristics, transport patterns, and attitudes towards COVID-19; 2) experimental condition measures; and 3) participants'

feelings of worry about COVID-19 infection. Participant data included their gender, age, country of residence, educational level, and commuting mode before and after the onset of the pandemic. Additionally, COVID-19-specific data was collected. This included information on participants' self-declared level of use of face masks on public transport, whether they are or live with someone classified as 'high-risk' with respect to COVID-19 exposure and susceptibility, their known prior proximity to a person infected with COVID-19, and having been infected themselves at any point. Experimental conditions included treatment status, image category (from 1 to 20), image order of appearance, time of each response, and date of participant access to the experiment. 'Worry' was represented by the stated worry of COVID-19 infection felt in the scenario presented in each image (see Supplementary Table 1 for variable descriptions).

3.4. Data analysis

Mixed regressions (fixed-effects and random intercepts) were used to identify significant differences between CSM effects. Random effects at the individual level controlled for differing baseline levels of worry of COVID-19 infection between participants. Four fixed-effect controls were applied: 1) at the image level – to account for each image having a potentially different average score; 2) the order of appearance – to account for the fact that image ratings might depend on the sequence of appearance; 3) date of response – to account for evolution of the pandemic, which may have impacted participants' perceptions; and 4) participant city – to be able to account for differing COVID-19 infection rates, deaths, and policies in each country that might influence responses. The resultant model took the following form:

$$\mathrm{Worry_{ij}} = \beta_1 \mathrm{Compliance_i} + \beta_2 \mathrm{X_i} + \mathrm{U_j} + \mathrm{E_{ij}} \quad (1)$$

where $Worry_{ij}$ is the declared perception of worry of COVID-19 infection of participant *j* for image *i*. Compliance is a categorical variable from one to four if the *i*th image contains an empty transport space, one for an image with no compliance, two for partial compliance, and three for full compliance. β_1 is the coefficient of interest that captures the impact of CSMs on participants' worry of COVID-19. X_i is the fixed effects of image ID, order of appearance, date of response, and city of the respondent for the *i*th image rated. U_j is the random intercept associated with the *j*th individual. E_{ij} is the error term.

Note that groups of participants rating different CSM scenarios were comparable in observable and unobservable characteristics. Two strategies were deployed to ensure that the presented images were the only element measurably influencing participants' responses. While the randomization of images ensures that the control and treatment groups are balanced and comparable, an empirical proof of this provides further validity. Statistical tests were therefore conducted to check that control and treatment groups were balanced across CSM scenarios for the 19 transit spaces in all observable characteristics for each CSM. Of the 144 balance tests, 3 were significant at 5%, which represents successful randomization. As the observable characteristics are balanced, by extension, unobservable covariates are also expected to be balanced. Therefore it is fair to assume that the groups rating CSMs are indeed comparable. Additionally, the regression analyses were first conducted without and then with controls, including all twelve covariates. Estimations of worry of COVID-19 infection that remained stable to the addition of all relevant observable covariates in the model are presented (see Supplementary Material).

In the following section, worry rating results are compared against the established baseline of worry of COVID-19 infection in an empty public park space. Only results that present a significant difference above 5% in both mixed-regression models with and without controls, and whose estimates remained stable in both models, are discussed.

4. Results

4.1. CSM and Worry ratings

4.1.1. Public transit space induces COVID worry

This experiment reveals that, compared to unpopulated parks, transit spaces are perceived as unsafe with respect to risk of coronavirus contraction, even when empty (worry estimate [W] = 1.637, P < 0.001) (Fig. 1a). Travelers are particularly worried about COVID-19 infection in enclosed (W = 1.368, P < 0.001), as opposed to open-air (W = 0.841, P < 0.001), transit spaces. This holds true even when these spaces are empty (Fig. 1b). Worry is particularly high within vehicle coaches (W = 0.528, p < 0.023), with no significant difference between areas of high human circulation (W = 0.0582, p = 0.786) and waiting spaces at platforms and bus/tram stops (Fig. 1c). Though all transit modes render higher levels of COVID-19 worry than the empty park baseline scenario, not all modes are equally concerning to riders. Worry is highest in metro (subway) spaces. Compared to metro spaces, worry is significantly lower in bus (W = −0.586, p = 0.004), train (W = −0.460, p < 0.030) and tram spaces (W = −0.928, p < 0.001) (Fig. 1d).

4.1.2. Full compliance with CSMs is needed to reduce worry

The incorporation of other people into transit spaces substantially increases traveler worry of COVID-19 infection associated with those spaces (W = 2.184, p < 0.001) (Fig. 1e). The results show that, along with reducing the probability of virus contraction, the combination of wearing face masks and social distancing significantly reduce worry of COVID-19 infection. However, for worry to drop sizably, all users of a space must comply with these CSMs (W = −1.227. p < 0.001) as conditions of partial compliance reveal only mild worry reduction effects for travelers (W = −0.260, p < 0.001) (Fig. 1f). As Fig. 2 shows, this requirement of full compliance with CSM to significantly reduce worry of infection is consistent across all the three cities studied (W-Milan: 1.545, p < 0.001; W-Santiago: 0.763, p < 0.001; W-London: 1.337, p < 0.001).

4.1.3. Neither hand sanitizer nor information provision reduce worry

Regarding the availability of hand sanitizer at metro and train stations and bus and tram stops, participants do not demonstrate a significant difference in worry of COVID-19 infection in scenarios where hand sanitizer was available, compared to cases in which it was not (W = 0.196, p = 0.271) (Fig. 1g). This lack of a significant impact is consistent across all transit modes (Fig. 3a). This result stands in opposition to the intuition that more people having the opportunity to use hand sanitizer means fewer, less heavily contaminated surfaces and therefore a lower perceived likelihood of infection. While a definitive explanation for this lack of impact cannot be made, one potential explanation is that hand sanitizer use is difficult to monitor in crowds. Because of this, individuals in this treatment group may have assumed low levels of hand sanitizer use by their fellow riders, despite its availability.

Similarly, the provision of information about the effectiveness of face mask use and social distancing in reducing COVID-19 infection fails to render a significant impact on passenger worry when compared to the case of no information provided (W = 0.339, p = 0.074) (Fig. 1g). This lack of significant impact against the no-information baseline treatment holds true even when delineated by transit mode (metro: W = 0.140, p = 0.534; bus: W = 0.028, p = 0.914; tram: W = 0.188, 0.445; train: W = 0.085, p = 0.686) (Fig. 3b).

4.1.4. Past contraction of COVID-19 makes people feel safer

At the time of this experiment, many people had contracted and recovered from COVID-19, and extensive vaccination programs were in the midst of being rolled out. Furthermore, cities were reaching herd immunity at different rates, and new variants were causing different parts of the world to exit and re-enter lockdown conditions in waves, as contagion risk ebbed and flowed. This raises the question of how worry

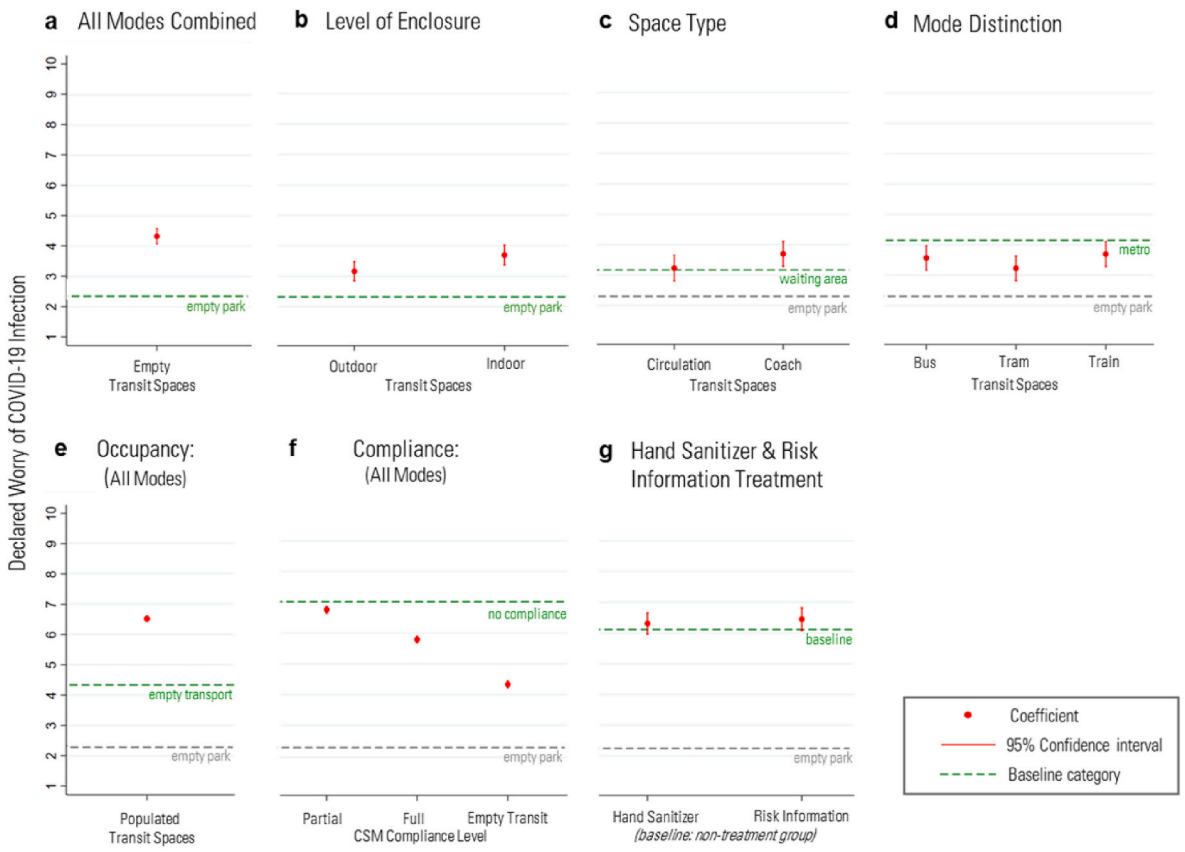

Fig. 1. The declared worry of COVID-19 infection across different public transit scenarios. Results are presented on a 1 to 10 scale where 1 represents "not worried at all" and 10 "extremely worried". **a**–**g**, Results are shown for the following explanatory variables: empty transport (**a**); level of enclosure in the space (**b**); type of public transit space (**c**); public transit mode (**d**); occupancy across public transit mode (**e**); level of travelers' compliance with CSMs (**f**); and provision of hand sanitizer and CSM risk-reduction information (**g**). The regression coefficients are represented by dots and 95% confidence intervals around coefficients. Mixed regression estimates with controls can be found in Supplementary Tables A1-A7 **c-g** plot in grey the mean of the empty park category (W = 2.69) as a reference point of minimal worry of COVID-19 infection in a public space.

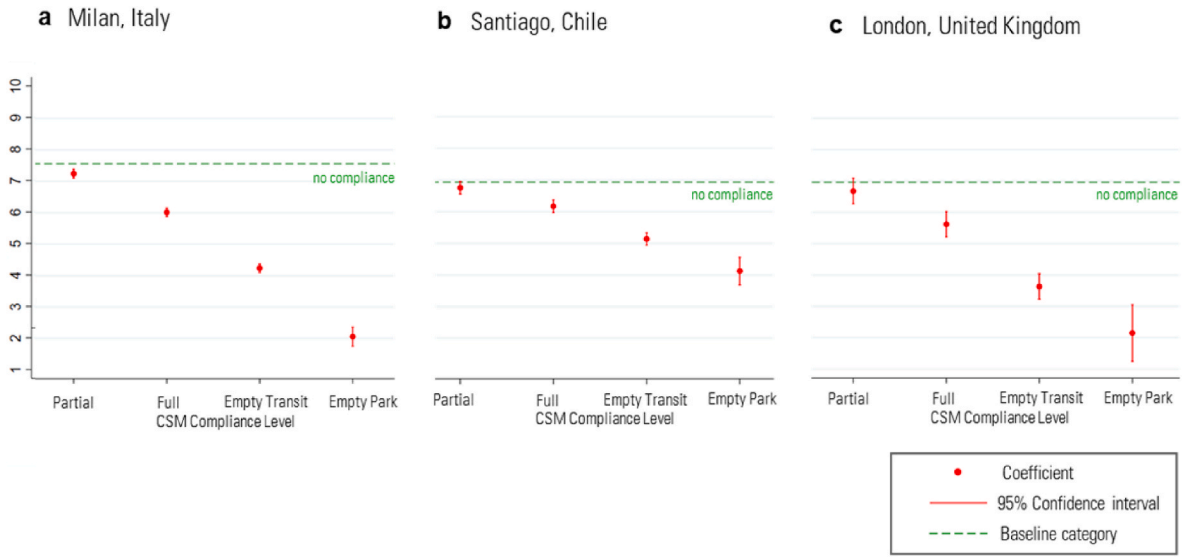

Fig. 2. The declared worry of COVID-19 infection across different public transit scenarios. Results are presented in a 1 to 10 scale where 1 means "not worried at all" and 10 "extremely worried". **a**–**c**, Results are shown for the level of travelers' compliance with CSM in (**a**) Milan; (**b**) Santiago; and (**c**) London. The regression coefficients are represented by dots and 95% by error bars around coefficients. Mixed regressions estimate with controls can be found in Supplementary Table A8.

is impacted by CSMs under different conditions of immunity. To inform this question, this experiment analyzed worry of COVID-19 infection among those who have the highest likelihood of functional immunity by way of having previously contracted and recovered from the virus (Dan et al., 2021). While it is understood that previous contraction of COVID-19 does not render an individual fully immune to re-contraction,

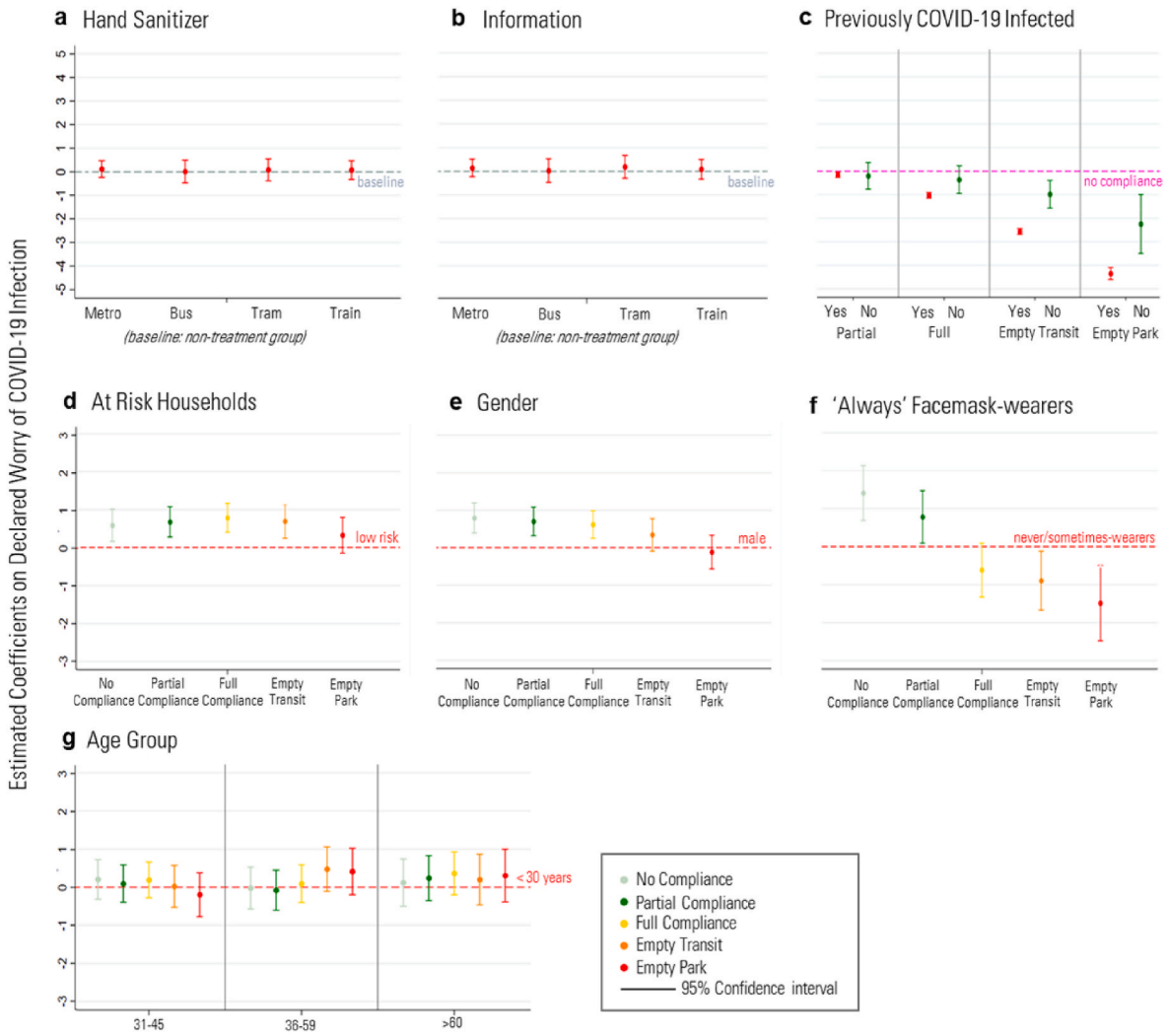

Fig. 3. Estimated effect sizes of various explanatory variables on travelers' declared worry of COVID-19 infection. For all graphs the estimated effect size for each explanatory variable shows the difference in points compared with a baseline category represented by a horizontal line. Estimated effect sizes are derived from mixed regressions. An effect size of <0 suggests that a given variable reduces travelers worry of COVID-19 infection compared with the baseline, and if it is > 0, the variable increases worry. 95% confidence intervals are represented by error bars around coefficients. a–f, Results are shown for the following explanatory variables: availability of hand sanitizer for different public transit modes (a); provision of information about the effect of CSMs on risk of COVID-19 infection (b); whether the traveler had previously contracted COVID-19 or not (c); whether the traveler lives with a person classified as clinically extremely vulnerable (d); gender of the traveler (e); the level of the travelers' use of face masks in public transit (f); and the age group of the traveler (g). Mixed regression estimates with controls can be found in Supplementary Table A9-A14.

particularly given the spread of variants of the virus, the low number of cases of confirmed re-infection do suggest that those previously infected are likely to be particularly resilient against future infection (ibid.). In this sense, using previous COVID contraction as a proxy for immunity – and more specifically, for the *perception* of immunity – is reasonable. Within the participant cohort, 5% were classified as immune via this prior-contraction proxy.

Among these perceived immune participants, just as among those who had never knowingly contracted COVID-19, worry of infection is higher in public transit spaces than in the empty park scenario, even when those transit spaces are empty ($W = 1.426$, $p = 0.011$). However, in both cases, overall worry levels are lower among the immune than the non-immune: when compared against a baseline of non-compliance, neither partial ($W = 0.202$, $p = 0.480$) nor full compliance ($W = 0.365$, $p = 0.222$) with CSMs have a significant impact on worry for travelers who have previously contracted the virus (Fig. 3c).

4.1.5. Household risk, gender, and behavioral patterns

Households in which at least one member is highly vulnerable (e.g. people who are undergoing cancer treatment, who have a respiratory condition, or who are immunocompromised) have a higher level of worry of contracting the virus in transit spaces than households with no highly vulnerable members ($W = 0.667$, $p < 0.001$) (Fig. 3d). None of the different levels of CSM compliance have a significant impact on this outcome. Furthermore, women worry more about contracting the virus in transit spaces than men ($W = 0.655$, $p < 0.001$), and again, CSM adherence does not have a significant effect in reducing this gendered difference (Fig. 3e).

Compared with those who sometimes or never wear face masks in transit spaces, travelers who always use a face covering are more worried about infection in scenarios of no compliance ($W = 1.410$, $p < 0.001$) and partial compliance ($W = 0.783$, $p < 0.026$). This gap closes, however, in a full-compliance scenario ($W = -0.615$, $p = 0.088$), supporting the claim that the correct face mask wearing has worry-mitigating impacts not only as a measure of perceived self-protection, but also as an observed collective behavior (Fig. 3f). Finally, regarding age, no significant differences in worry of getting infected are found across different age groups in the participant cohort (31–45 years: W =

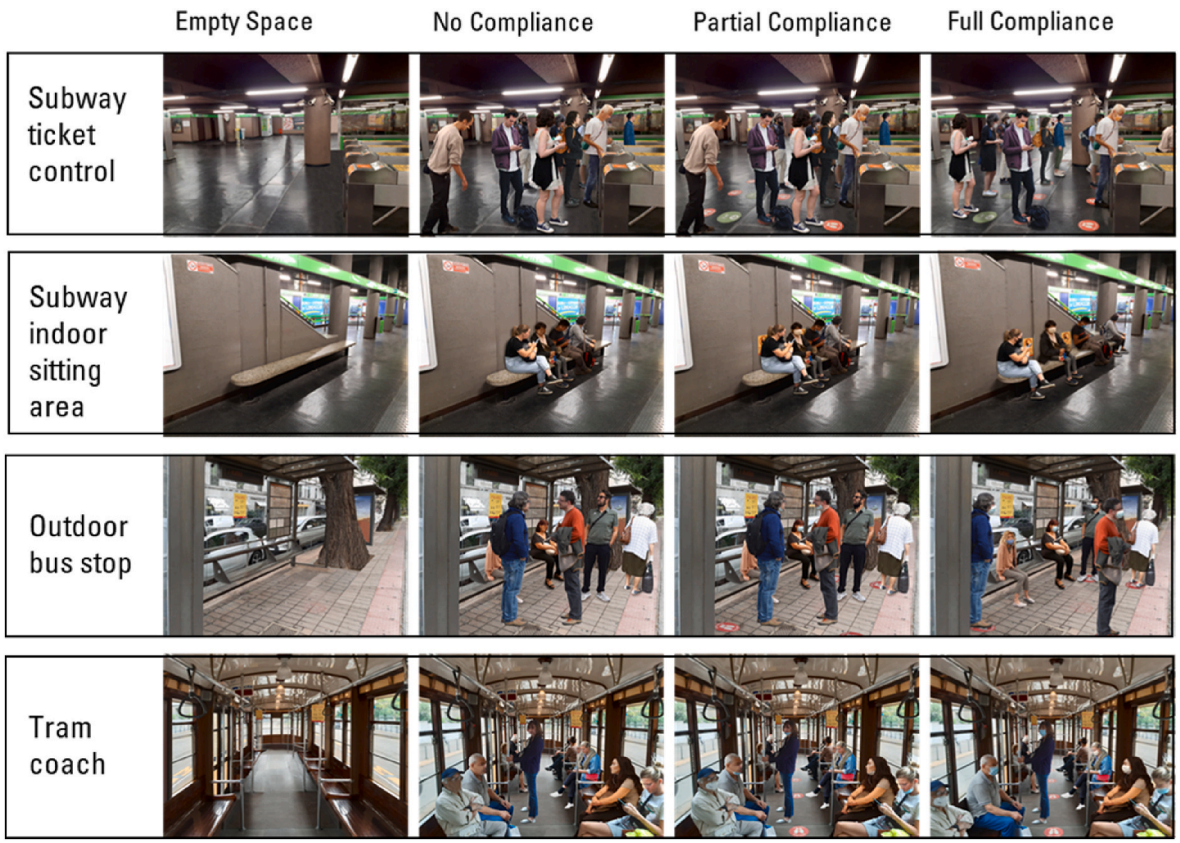

Image 1. Example of photographic simulations of compliance with COVID-19 safety measures.

0.173, p = 0.410; 46–58 years: W = 0.028, p = 0.900; >60 years: W = 0.270, p = 0.286); this is true for the results overall, and also when considering scenarios with different levels of compliance with CSMs (Fig. 3g).

4.2. Limitations

This experiment relies heavily on the use of digital images to represent real-world transit experiences. This was primarily due to an inability to conduct studies in the field due to travel and lockdown restrictions. Video and sound were not included, as we were unable to guarantee via the virtual experiment platform that people would in fact listen to any audio offered, or watch any videos in full. More comprehensive results might have been obtained in more immersive scenarios that more closely mirrored real life. Nonetheless, this image-based experiment serves as a suitable, if conservative, proxy, as studies show that image evaluation is correlated with real-life emotional reactions (Rossetti and Hurtubia, 2020; van den Brink et al., 2017).

Additionally, the scenarios simulated in this experiment unfortunately do not reflect transit images that are well-representative of the majority of transit spaces within each of the different participant cities. The images supporting the photo simulations were derived from particularly well maintained transit areas in central Milan. The images all showed appealing, clean, well-lit transit realms. While these features may be accurately representative of some transit spaces, it is unlikely that they accurately reflect the majority of transit spaces that participants encounter. Future iterations of this experiment should strive for images that most closely mirror real-life transit experiences. While we keep cleanliness levels constant for each public transport space, it may be the case that cleanliness itself is as a relevant factor in affecting worry of COVID-19 infection, and thus the results of this study might vary across different contexts of cleanliness.

Further studies could investigate this effect, modifying the image conditions to photo-simulate different scenarios of cleanliness.

Crowdedness is one additional factor that deserves further attention. Commuter surveys show that reducing crowdedness in coaches is an important measure to increase transit use following the pandemic (Global Public Transport Report 2020). However, any policy change in this direction would need to be contrasted with the potential counterbalancing effect on personal safety concerns. That is to say, while a reduction in ridership volumes may make riders generally feel more COVID-safe, reduced ridership may cause some riders – notably women-identifying riders (Loukaitou-Sideris and Fink, 2009) and members of other socially vulnerable populations (Brownson et al., 2001; Clancy et al., 2001; Craig et al., 2002) – to feel less physically safe irrespective of the coronavirus. Unfortunately, testing the intersections between COVID-specific and non-COVID-specific safety concerns (e.g. crowdedness, time of day/night of travel) goes beyond the financial restrictions of this research, as it would have necessitated a significant expansion of the number of photo-simulation scenarios (CSMs x Crowdedness; CSMs x Night Conditions; CSM x Crowdedness x Night Conditions) and of the experiment's sample size. These broader intersecting rider worries, though a limitation in this particular research, would be a worthy focus of future photo-simulation randomized control trial studies.

In this study, the potential impact of sharing information with riders regarding increased ventilation throughout transit spaces is not tested. This choice was made because this CSM – ventilation information dissemination – though present in some systems (e.g. Washington Metropolitan Area Transit Authorit), is not one of the more widely used across the world's transit networks. Still, given the efficacy of ventilation practices in lowering spread rates of COVID-19 in indoor spaces, as emphasized by studies from a range of research disciplines (Sun and Zhai, 2020; Fadaei, 2021; Querol et al., 2022), not testing the effects of improved ventilation and information dissemination on levels of worry in transit environments remains a relevant limitation of this research.

While data was collected from participants in London, Milan, and Santiago, direct cross-city comparisons of findings unfortunately cannot be made. Since data was collected from participants recruited through paid social media advertising, the participant sample is not representative of each city's general demographics. While this experiment, as with any randomized controlled trial, still has high internal validity, future studies could conduct this experiment on a more representative sample to overcome this limitation.

Finally, while CSMs might reduce the worry of COVID-19 infection, there remains the possibility that these measures have the opposite effect, inducing or increasing worry. For example, by simply seeing others wearing face masks, travelers may be reminded of their risk of infection, in turn raising their levels of worry. While this research accounts for this potential bi-directionality by estimating the aggregate effect of CSMs via comparison of full, partial and no compliance scenarios, it cannot disentangle the specific impact of CSMs as facilitators of worry from their impact in reducing worry of virus infection.

5. Discussion and conclusion

Perceiving transit to be a high-risk mode of transport for COVID-19 infection, many travelers have switched to private vehicular modes. If this modal switch persists, the financial sustainability of public transit, as well as the social and environmental benefits it facilitates, stand in jeopardy. While most public transit agencies have, at some point in the pandemic, implemented measures to offer a higher likelihood of safe travel through transit spaces – the most common being compulsory face mask wearing, the presence of physical distancing markers, and the provision of hand-sanitizing equipment – it is unclear whether their capacity to provide travelers with a decreased perception of risk is pervasive enough to encourage a return to transit. This assessment of traveler worry regarding COVID-19 infection in transit spaces, and the ways in which the aforementioned COVID safety measures impact these feelings, offers some insight.

This work's central finding is that across all transit modes, mask-wearing and social distancing measures do indeed significantly decrease riders' worry of infection, but that that impact is dependent on the full compliance of travelers with these CSMs. It is worth noting that this effect is not observed for the population with perceived immunity to COVID-19. Still, the all-or-nothing nature (full compliance vs all other levels of compliance) of this finding suggests that CSMs should continue to be required as perceptions of immunity – be that from vaccination or having contracted and recovered from the virus – increase globally; notably in countries where vaccination rates remain low, and as new variants of the coronavirus appear. Furthermore, these results prove consistent across all three cities studied suggesting that full-compliance is required to reduce worry of infection across a diversity of cultural, social, and COVID-19 trend contexts.

In the absence of full trust in other travelers to comply with all CSM regulations, enforcement is likely necessary to effectively reduce traveler worry. Careful attention should be paid to exactly what form this CSM enforcement takes. Thus far in the pandemic, several different enforcement practices have been tested with varied levels of success. In some cases vehicle operators have been tasked with enforcement of face mask wearing, leading in some instances to their being verbally berated, physically assaulted, or forced to suspend and interrupt services to deal with non-compliant passengers (Schultz and Bryon, 2021). Though common in the early stages of the pandemic, this practice has gradually been abandoned due to drivers expressing discomfort with the resulting confrontation and fear of physical endangerment, as well as inconsistencies in strictness of adherence to regulations across operators, and union disputes over drivers taking on additional responsibilities without additional compensation (Kershner and Johnston, 2021). In other cases, law enforcement agents – i.e. police officers – have been tasked with enforcing mask wearing in transit spaces. In these cases, the penalty for non-compliance has most commonly been a fine and removal from the vehicle or transit station (Topham, 2021). This method has similarly been deemed unsatisfactory. In addition to accounts of violence towards police and discomfort with increased police presence in public space associated with feared brutality and misconducted by police (Schultz and Bryon, 2021), low officer capacity and low willingness to enforce have contributed to particularly low compliance rates – often below 50% – in several municipalities using this approach (ibid.; Phillips, 2020).

Southeastern Pennsylvania Transportation Authority (SEPTA), transit provider for the Greater Philadelphia Area, has taken a unique approach to face mask enforcement across their network, deploying what they call a "speak-softly-and-carry-a-box-of-masks" technique (Fitzgerald, 2021). In this strategy, enforcement is handled by SEPTA employees from many departments. Some are planners, some are administrators, and some are social workers initially hired to facilitate connecting those using SEPTA facilities for shelter with social services (Suzukie, 2020). These workers directly distribute masks and offer COVID-safety educational materials within their assigned transit space to any people not wearing a face covering. There are no fines or removal penalties if passengers refuse to engage with workers or wear the free mask. In January 2021, SEPTA conducted a 4000-rider compliance audit across their subway trains, buses, and trolleys, with a compliance rate of 90% reported (Fitzgerald, 2021). Innovative strategies like this that pull from a wider-reaching workforce – or that employ an entirely new workforce – and encouraging face mask use through the deployment of individuals trained in de-escalation, customer assistance, consensus building, and education techniques may be a sustainable and effective way forward in the future of the pandemic (Suzukie, 2020; Kershner and Johnston, 2021).

The question of the best placement of enforcement efforts within transit spaces is also important. Findings reveal that feelings of worry vary across different transit modes and commuting spaces: subway areas are associated with the highest levels of worry, and tram spaces the lowest. Moreover, worry is at its highest in transit spaces that are enclosed and host high levels of human circulation, particularly within carriages. This suggests that transit providers would see the largest impact on riders' COVID-related worries if enforcement efforts were concentrated in subways, on board vehicles, and in tight, hallway spaces. This differs from current practices, as most systems with enforcement in place focus those measures at station entrances with little specificity across mode types.

The enforcement of social distancing presents particular difficulty, as its success functionally conflicts with transit service capacity – when vehicle frequency remains the same, or with operational cost – when vehicle frequency is increased. Both cases impact the financial sustainability of transit agencies. Providers will no doubt need to balance the value of these trade-offs. Nonetheless, different enforcement, encouragement, and incentivization techniques have resulted in different levels of compliance. These variations can inform agencies going forward. In particular, floor and seat markers that can be stood or sat on, and in that sense can be functionally ignored, have rendered lower compliance rates than spacing designs that make non-compliance physically difficult or impossible (Nocco et al., 2020). Design solutions, as opposed to enforcement personnel, then could be prioritized by agencies addressing social distancing across their infrastructure.

Though this study's findings encourage the continued implementation of face mask and social distancing CSMs, the use of hand sanitizer and provision of information regarding CSM efficacy are measures that could be lifted and/or remain unenforced without a major effect, at least with respect to their role in impacting rider worry. Both of these measures demonstrated no significant impact on feelings of worry across any socio-demographic categorization, across any transit mode specification, or across compliance levels. This aligns with past research that has found inconsistencies between transit riders' interpretation of information provided to them. Dong et al. (2021), for instance, found that some riders take comfort in increased knowledge regarding COVID-19,

while for other riders, an increase in knowledge led to sensationalizing and catastrophizing. These directionally competing outlooks may contribute to the finding that provision of COVID risk reduction information in public transit spaces led to no significant impact on worry about infection within this experiment.

In line with results from existing literature (Zafri et al., 2022; Gnerre et al., 2022), this experiment finds that levels of perceived risk vary by gender. Travelers who identify as women experience significantly higher levels of worry in populated transit spaces than those who identify as men, and CSMs do not have a significant impact on mitigating this gender disparity. Additional findings confirm results of past studies at the intersection of risk perception and health vulnerability (He et al., 2021), concluding that members of households in which an individual is immunocompromised or highly COVID-vulnerable are more worried about infection in public transit than members of otherwise lower-risk households. As in the case of gender, CSMs fail to significantly shrink the worry-gap between these two groups. Results further reveal that people who always comply with face mask rules are more worried about contracting the virus in these spaces, however this disparity closes when all other commuters abide with CSMs. It is in this last cohort where we may see the continuation of CSMs being more effective in retaining or bringing back rider numbers. These findings can help informing transit providers of disparities in the effects of CSMs, allowing them to make informed decisions around implementation of measures in future.

An element of hope can be extracted from the finding that those who have already contracted and recovered from COVID-19 at some point during the pandemic are less worried about contracting COVID in transit spaces than those who have not, with CSMs no longer having a significant impact on this group. In keeping with the previously discussed connection between worry and mode choice, this suggests that, as a larger share of the population has at some point either contracted and recovered from COVID-19 or has been vaccinated, transit agencies can reasonably expect an increase in ridership. Further research is needed, however, to project the magnitude of riders expected to return under scenarios of different scales of immunity proliferation.

Finally, it is important to note that while a safe return to high capacity operations may be necessary to reverse the current downward spiral of transit (Sadik-Khan and Solomonow, 2020), CSMs – their design, duration, enforcement structures, and the combination of measures used – are on their own unlikely capable of returning ridership to pre-pandemic levels. CSMs only tackle a piece of the ridership puzzle. It is possible that ongoing changes to working, schooling, and recreational practices continue to alter the transit-use landscape for the foreseeable future. As such, a more structural rethinking of how our transit systems function may be required to regain healthy, sustainable ridership levels.

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Author contributions statement

Pablo Navarrete-Hernandez: Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Project Administration, Data Curation and Visualization, Writing – Original Draft Preparation. Lindiwe Rennert: Resources, Formal Analysis, Writing – Original Draft Preparation, Writing – Review and Editing. Alessandro Balducci: Conceptualization, Methodology.

Ethical considerations

All experimental protocols were approved by a the Politecnico di Milano Ethical Committee held on November 5th, 2020. All participants signed an online informed consent form.

Declaration of competing interest

None.

Data availability

The authors do not have permission to share data.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tranpol.2022.11.011.

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