Where and how often do people touch train interiors? An Investigation for future pandemic prevention

Abstract

The Covid-19 pandemic highlighted infection and hygiene as risks in dense public spaces, including public transport vehicles. This study investigated passenger touching behaviour within metro vehicles to understand the fomite exposure of passengers. Using in-vehicle CCTV on three lines of the London Underground, this paper investigated the number of touches on different types of train interiors and investigated their relationship with passenger density and movement. In total, 1,818 station sections and 16,891 passengers were observed cumulatively from May to December 2021. The results showed that on average for each type of interiors on Victoria and Jubilee lines, there were between 0.07 to 0.57 touches per passenger movement (i.e. boarding or alighting) for deep tube lines, whilst District line that uses larger carriages showed a different tendency. The results also suggested that for deep tube lines, the number of touches per person increased beyond a density of around 1.5 standing passengers per square meter possibly because passengers may touch interiors more in order not to bump into other passengers. These findings can be used in infection risk modelling and can inform mitigation of infection risk of future pandemics.

Keywords

pandemic, fomite infection risk, passenger behaviour, surface touches, railway and public transport systems, UN SDG 3, 9, 11

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1. Introduction

Public Transport is expected to play a major role in addressing global challenges, such as climate change and urban sustainability. The Covid-19 pandemic has made us aware of the risk involved in use of dense public spaces, including public transport vehicles. Transport systems around the world have managed to overcome this challenge (Chiscano & Darcy, 2022; Jenelius & Cebecauer, 2020; Mogaji et al., 2022; Tirachini, 2020)). As Covid-19 is the most recent pandemic that has occurred in the modern era and is unlikely to be the last, it is important to build a knowledge base on how people use space and interiors in transport vehicles and future-proof public transport systems, which will serve as an essential means of moving around for key workers and other people who have to travel (Chen et al., 2021; Linka et al., 2020; J. Zhang et al., 2021).

Existing studies have suggested two routes of potential infection: airborne and fomite transmissions, for example (Cheng et al., 2022a; Greenhalgh et al., 2021; Ji et al., 2022; Miller et al., 2022; Shinohara et al., 2021; Xiao et al., 2017; Zuo et al., 2020). The risk of airborne transmission varies based on air quality (Adhikari et al., 2021; Cheng et al., 2022b; Gao et al., 2019; Katre Pallavi et al., 2021; Ou et al., 2022), which in turn depends on factors such as passenger volume, ventilation, and exterior environment(Liu et al., 2020; Ou et al., 2022; Peng et al., 2022). As for potential fomite transmission, landed droplets touched by hand are thought to be one of the main infection channels (Armand & Tâche, 2022; Miller et al., 2022; Nicas & Best, 2008; S. J. R. Silva et al., 2021; N. Zhang, Wang, et al., 2021; N. Zhang & Li, 2018). There have been studies on the presence of Covid-19 viruses on public transport (Caggiano et al., 2021; Cheng et al., 2022c; Guadalupe et al., 2021; Luo et al., 2020; Otter & French, 2009). In railway carriages, fragments of viral load have been found across samples taken in different countries(P. G. da Silva et al., 2022; Green et al., 2021; Hadei et al., 2021; Moreno et al., 2021; Xu et al., 2022). Whilst these studies have suggested surface contamination in public environments, surprisingly, there has not been much empirical research on how people touch surfaces except in a limited types of environments including hospitals (Huslage et al., 2010; Wang et al., 2021; Yatmo et al., 2020) and restaurants (N. Zhang, Chen, et al., 2021). There has been little evidence of how passengers touch surfaces in public transport vehicles including trains even though they are used by the wider public. Whilst these hospital and restaurant studies could imply where people would touch (i.e. places where people in motion need to touch to keep balance), there remain important questions that include 1) how often passengers touch (because fomite infection risk would increase accordingly), and 2) whether touch behaviour is influenced by passenger density (because crowd management can be an infection control measure).

There have been studies on passenger behaviour within railway carriages, most of them focusing on boarding and alighting behaviour (D'Acierno et al., 2017; Davis Associates, 2008; Oliveira et al., 2019; Seriani et al., 2019, 2022). In crowded situations, passengers experience and tolerate the perception of crowdedness differently with different avoidance techniques and interactions (Cho & Park, 2021; Hirsch & K. Thompson, 2011; Kunimatsu et al., 2020; Shelat et al., 2022). Such existing studies have offered useful insight into crowd and rail capacity management but offer little evidence as to potential virus infection. Vargas-Robles et al., (Vargas-Robles et al., 2020) conducted a microbiological observation where 120 passengers were shadowed by researchers in Mexico City metro and their touching behaviour (including touches on their bodies and clothes) was recorded, but where passengers touched inside the vehicle was not recorded. Hirsch et al., (Hirsch et al., 2021) conducted a survey on whether passengers would change their touching behaviour if the information on whether other people have already touched there, but it did not analyse where passengers touched.

The present study concerns passenger behaviour from the viewpoint of potential fomite infection. This research analysed passengers' surface touch behaviour on metro vehicles and used London Underground as a case study. The motivation is that whilst metros are frequently used by a wide range of people, their conditions (such as frequent acceleration and braking) can induce unique touching behaviour, thereby leading to different profiles of fomite exposure. Such evidence can be used to model fomite infection in future pandemics as well as to develop measures to control it. It should be noted that this study focuses on passenger touching behaviour, and hence assessment of the viability of fomite particles as viruses is outside the scope of this study. In the following chapters, the paper first explains the method used, and then analyses the results from the viewpoints of touch frequency and its relationship with passenger density, followed by discussions.

2. Method

2.1 Data source

CCTV footage of District Line, Jubilee Line, and Victoria Line from three time periods during the easing of covid restrictions was provided by Transport for London (TfL), which manages the London Underground. Note that carriages for Jubilee and Victoria Lines were smaller than those for District Line. The observation periods were weekdays in April and May 2021 for District Line, October and November 2021 for Jubilee Line, and November and December 2021 for Victoria Line. The choice of these lines and the observation periods was made in consideration of the rolling stock types as well as operational requirements and staff availability of TfL. In total, eight trains on District, two trains on Jubilee, and three trains on Victoria were observed. For each observed train, one carriage is randomly selected and the CCTV footage of that carriage from the beginning of the day to the time point where the researchers got on for manual checks was analysed. This timing was chosen because of our intention to correlate the results of this paper with the degree of surface contamination, which is published elsewhere (Seo et al., 2023). This resulted in the sum of the video durations of 10 hours for Jubilee, 15 hours for Victoria and 25 hours for District. The numbers of observed passengers for the three lines were shown in the Result section. Note that the study successfully went through the required processes of Data Protection Impact Assessment ((Transport for London, 2020); UCL reference no. Z6364106) and Ethics approval (UCL 0119.009). All the agreed privacy controls were followed thereafter: CCTV footages being cut for each station section and randomised before video observation, which made it impossible to track whether a passenger observed in one section was present in previous sections.

2.2 Train carriage layout and observation area

Observations were carried out based on an observation area that was set by the researchers and that can be seen from multiple cameras to avoid occlusion issues. Any passenger seen leaving the observation area was counted as such and excluded from the data. The plans of the carriage shown in Figure 1. The rectangles in the figure show the boundaries of the observation areas. Images of the train carriages are shown in Figure 2.

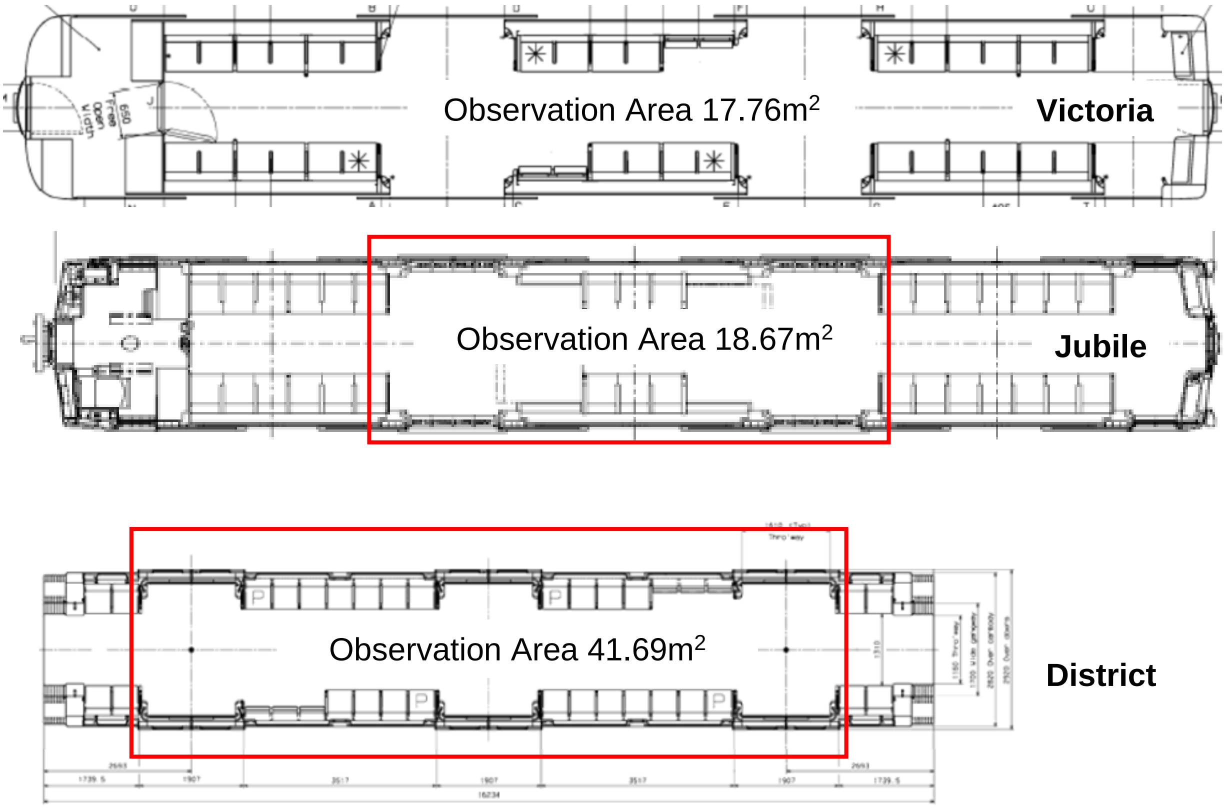


Figure 1.Observation area for the vehicles of each line. Drawings are obtained from Transport for London.

Figure 2. Train interior of District Line trains (left) and Victoria Line trains (right). Jubilee Line trains are similar to those of the Victoria Line. See Skuce, P (2014) and Skuce, P (2012) in the reference section.

The observation area for District line trains includes 28 observable seats, 13 standing handlebars (SHB) between seats and next to the glass by the doors, 6 overhead handlebars (OHB), and 3 middle standing handlebars (MSHB). Regarding Victoria and Jubilee line, there were 14 observable seats. Victoria had 12 SHBs, 6 OHBs, and 2 MSHBs, with Jubilee 18 SHBs, 6 OHBs, and 2 MSHBs. These are summarised in Table 1. These surface types were chosen because they were touched by passengers in pre-observations and touches on them were identifiable from CCTV. Touches on doors while passengers leaned on them, for example, were not always clearly identifiable and hence omitted from the observation. Note that the sectional area (including the height) of trains for Victoria and Jubilee lines is smaller than that for District line because of the smaller tunnel sectional area of the lines.

Table 1. Number of seats and interiors in observation area

	Seats	Standin handle Bars (SHB)	Overhead Handlebars (OHB)	Middle Standing Handlebars (MSHB)
District Line	28	13	6	3
Jubilee Line	14	18	6	2
Victoria Line	14	12	6	2

2.3 Data collection

For each video, 1) passenger movement and 2) passenger surface touches were manually observed for each section between two adjacent stations from the moment where doors were completely closed at one station to the same moment at the next station. The observation was conducted by one researcher to keep consistency. The observer replayed once each clip at a very slow speed (and where necessary played it backwards) to identify the number of surface touches of each person in the observation area. The observer initially did a training as to how to observe videos where observation results were compared to video clip in which another researcher was present as a passenger in the video and touched surfaces. Regarding the passenger movement, the number of movements made by passengers is separated into the following: boarding, alighting, standing up before leaving, standing, and sitting. The sum of movements refers to the boarding and alighting movements only. Passenger surface touches on train interiors were recorded by observing the movements of the hands of passengers. On the video, if a passenger's hand had physical contact with a relevant train interior, it was regarded as a touch. Such touches did not take account of duration; for example, if a passenger held a part of the handlebar for a long time, it was still regarded as one touch. If this person moved his/her hand and touched a different part of the same handlebar, then this was considered as another touch. Density was calculated based on the number of people divided by the surface area (m^2) of the observation area.

2.4 Data analysis

The analysis included three parts. The first part investigated the number of touches and the number of passengers to gauge whether the number of passengers affected the number of touches. An ANOVA was performed to compare the three underground lines using IBM SPSS software. Secondly, whether or not the duration spent between stations affects the number of touches was investigated. With Microsoft Excel a linear regression analysis was performed on the relationship between the number of passengers and the number of touches observed between two consecutive stations for each type of interiors. Thirdly, whether different station sections had a role in affecting the number of touches was examined.

3. Results

3.1 Descriptive statistics

Table 2 shows the descriptive statistics. We observed 452, 223 and 1143 station sections for Victoria, Jubilee, and District Lines respectively. The total number of passengers observed across the three lines was 16,981. Note that these numbers were sums across station sections, and, for example, if a passenger (in the observation area) rode from a station to another station that was two stops away from the original, then they were counted twice. The average values were calculated by dividing the sum of each index (e.g., the number of touches on OHB) by the number of station sections. Jubilee has the highest OHB and SHB results on average at 2.49 and 2.77, followed by Victoria with 2.11 and 1.79. Table 3 shows the results of ANOVA on the averages of the number of touches across the facility types (i.e., comparing the averages of the three facility types for each line) as well as across the lines (i.e., comparing the averages of the three lines for each facility type). The results suggest a statistically significant difference between the facility types and the lines.

Table 2. Descriptive statistics

Per station	No. of passengers	Boarding	Alighting	Standing	Sitting	Sum of movements	OHB	SHB	MSHB
Victoria									
Total	3803	1680	938	1180	3302	1834	139	275	138
Average	8.41	3.72	2.64	2.61	7.31	5.52	2.11	1.79	1.48
SD	7.80	3.99	2.97	3.42	4.97	4.58	1.47	1.13	0.72
Jubilee									
Total	2651	462	382	589	2083	844	117	216	32
Average	11.89	2.08	1.72	2.65	9.33	3.80	2.60	2.73	1.07
SD	8.84	3.06	2.54	4.04	5.76	4.26	2.23	2.35	0.25
District									
Total	10527	2082	1697	592	9825	3779	28	175	130
Average	9.22	1.83	1.49	3.13	8.60	3.31	1.12	1.54	1.43
SD	7.68	5.19	4.86	2.85	6.90	9.41	0.33	1.03	0.88

Table 3. Results of ANOVA on the averages of the number of touches

Grouping	category	F	p-value
Across the facility types	Victoria	18.0	p<0.001
	Jubilee	15.0	p<0.001
	District	26.7	p<0.001
Across the line	OHB	91.5	p<0.001
	SHB	68.8	p<0.001
	MSHB	22.8	p<0.001

3.2 Relationship between the number of touches and the number of people

Figure 3 shows the relationship between the number of passengers divided by the area of the observation area (or density in the observation area) and the number of surface touches divided by the area for OHB, SHB, and MSHB across the three underground lines. Each data point is the record of a station section. There may be a positive relationship between the passenger density and the number of touches divided by the area for OHB and SHB, but such a relationship is not clear for MSHB. The average number of passengers across the all the clips of each line was shown in Table 2 (e.g. 8.41 for Victoria Line). The relationship between the number of touches and the number of 'standing' people was analysed, but the results were similar (and hence not presented here).

A linear regression model was developed for each interior type for each line where the independent variable was the number of passengers and the dependent variable was the number of touches. Table 4 shows the results. It can be seen that the models for Jubilee Line showed an R^2 value of 0.4 or more for OHB and SHB, but not for MSHB, while Victoria Line shows R^2 values of around 0.3 for OHB and SHB and 0.4 for MSHB. The R^2 value of models for District Line was below 0.1.

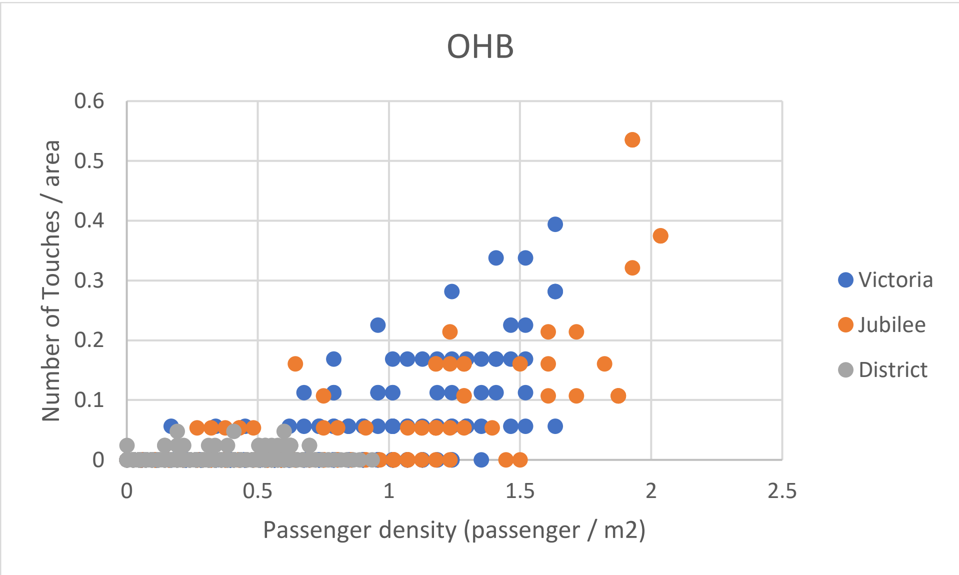


Figure 3(a) OHB

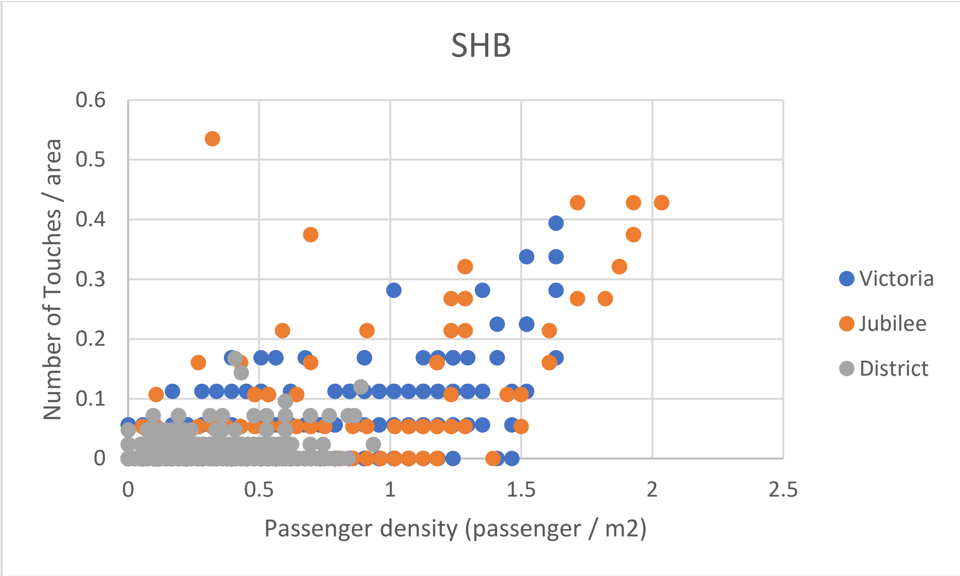


Figure 3(b) SHB

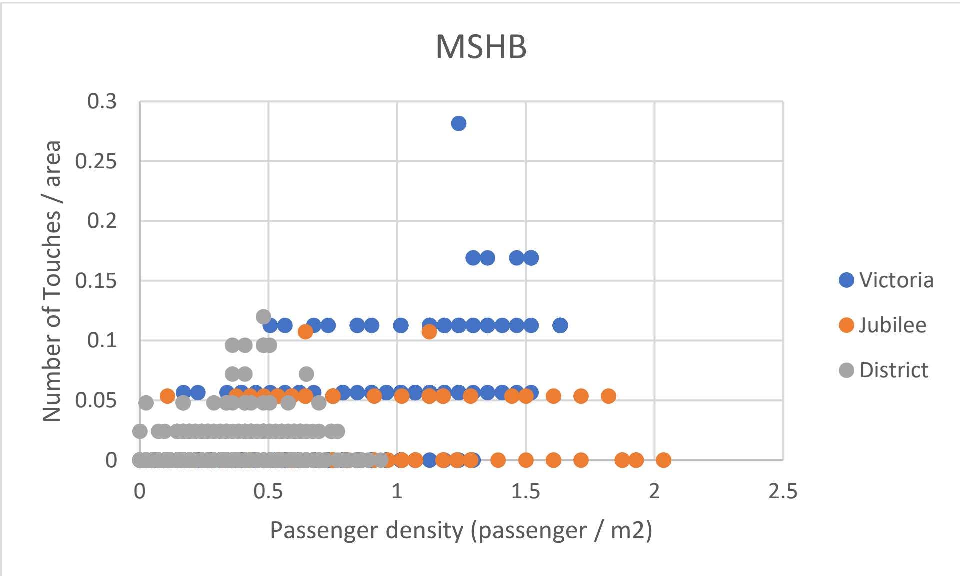


Figure 3(C) MSHB

Figure 3. Relationship between the passenger density and the number of touches divided by area observed between two consecutive stations, for OHB, SHB and MSHB

Table 4. Results of regression analysis for the number of touches

	Victoria Line			Jubilee Line			District Line		
	R^2	Intercept	Coefficient: Number of people	R^2	Intercept	Number of people	R^2	Intercept	Number of people
OHB	0.33	9.64	3.90 ($p<0.001$)	0.46	-0.79	0.11 ($p<0.001$)	0.03	-0.01	0.00 ($p<0.001$)
SHB	0.28	8.98	3.26	0.40	-0.65	0.14	0.06	-0.01	0.02

			(p<0.001)			(p<0.001)			(p<0.001)
MSHB	0.40	8.81	5.92 (p<0.001)	0.05	0.04	0.01 (p<0.005)	0.06	-0.03	0.02 (p<0.001)

3.3 Relationship between the number of touches per passenger movement for each facility type for each line

Table 5 shows the average number of touches per person movement for each facility type for each line. The number of person movements is defined as the sum of boarders and alighters, and was used in the analysis here because it was observed that passengers often touch facilities when they are boarding and alighting. The table shows that SHB was the most touched facility type, and District Line had a different trend (i.e. its touches on MSHB are higher than Victoria and Jubilee Lines) which may have reflected the difference in carriage designs. Figure 4 shows the relationship between the number of standing passengers in the observation area, and the number of surface touches for OHB and SHB per person movement between two consecutive stations. Touches for MSHB are not included as its trend may be different (Figure 3). The figures for Jubilee and Victoria lines suggest that the numbers of touches per person started increasing when the number of standing passengers reaches around 8 people. District line shows such a tendency for neither of them, which corresponds with the regression model results in Table 3.

Table 5. Average number of touches per passenger movement for each facility type for each line.

	OHB	SHB	MSHB
Victoria	0.070	0.158	0.085
Jubilee	0.132	0.230	0.042
District	0.054	0.572	0.428

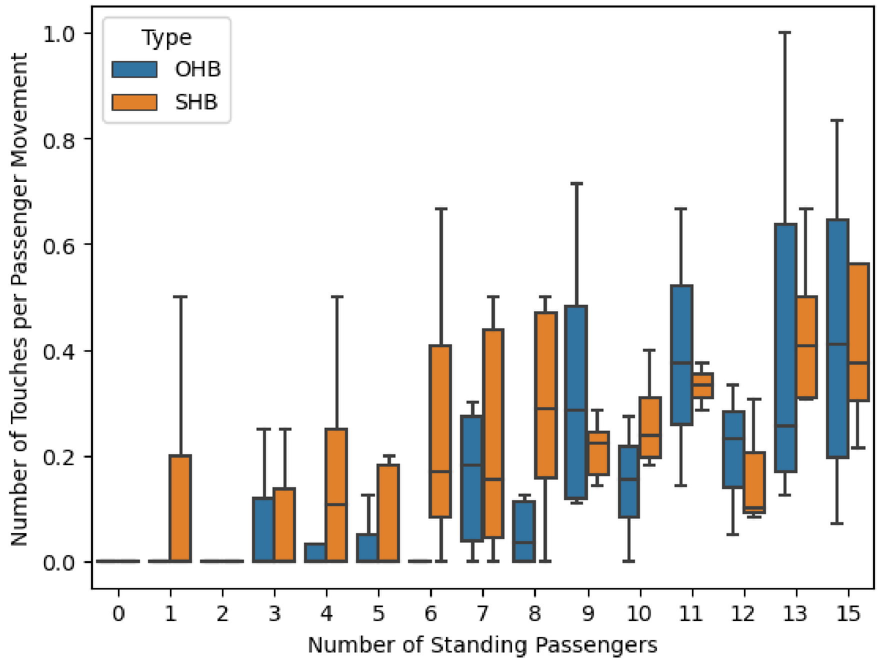


Figure 4(a) Victoria Line

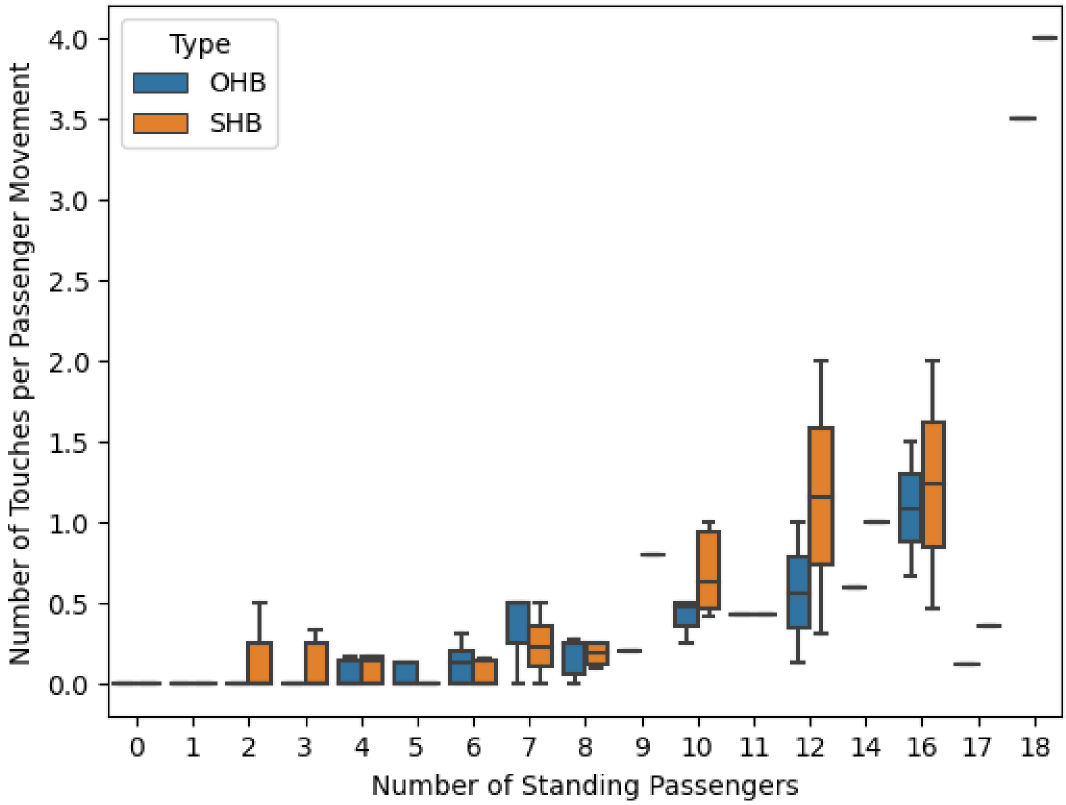


Figure 4(b) Jubilee Line

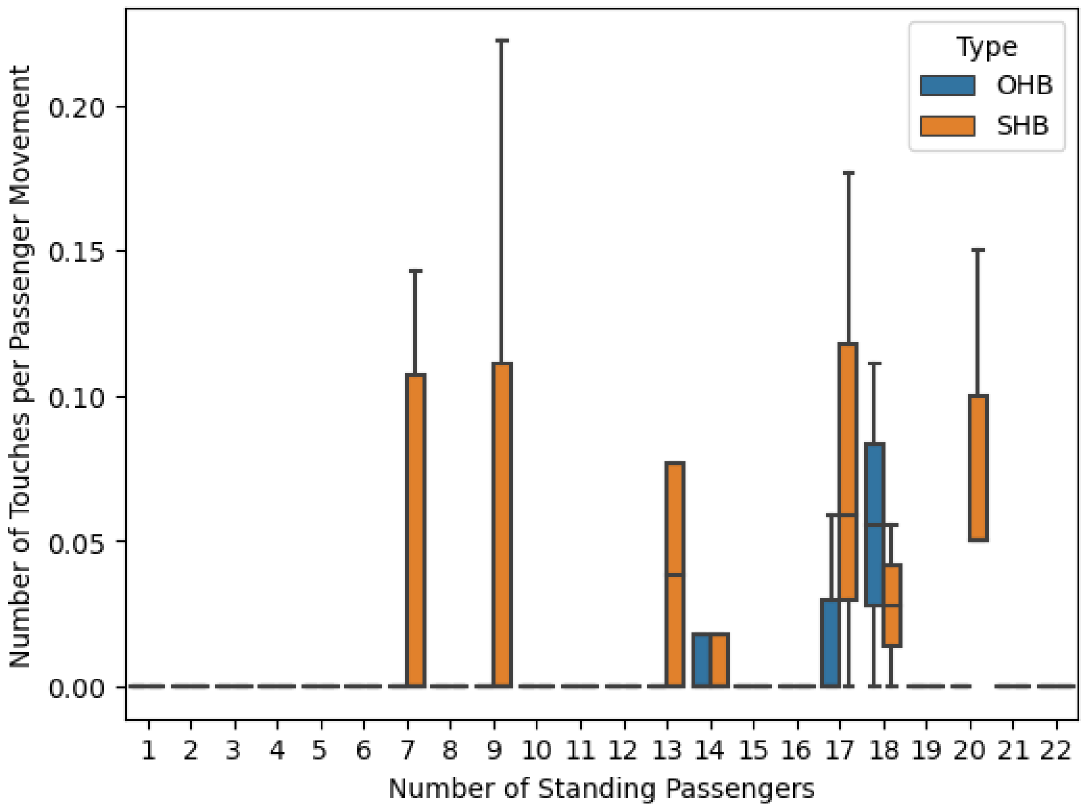
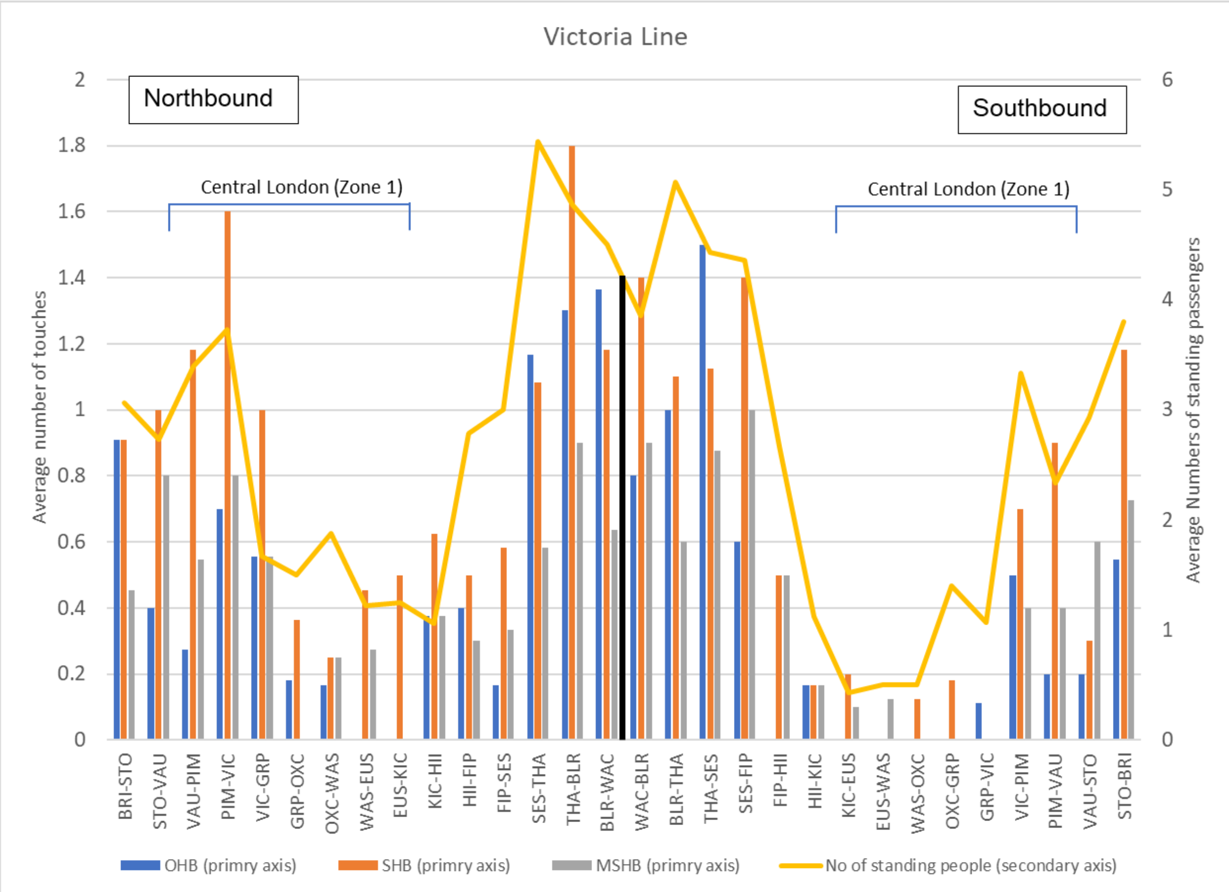


Figure 4(b) District Line

Figure 4. Relationship between the number of touches each passenger made on average between two consecutive stations and the number of standing passengers for each line

3.4 Number of touches (divided by the number of passengers) across station sections

Figure 5 shows the relationship between the number of touches divided by the number of passengers and the number of standing passengers across the station sections. The 3-character abbreviations for station names (e.g., BTX means Brixton) were used, with distinction between the different directions (e.g., northbound and southbound). Note that the numbers of passengers and movements are those when CCTV observations took place, and do not correspond to the passenger demand of the whole day. The results show that sections with many standing passengers had great numbers of touches per passenger. The numbers of touches per passenger were notably high on the Westbound Jubilee Line from SRA to BAS including the Central London section.



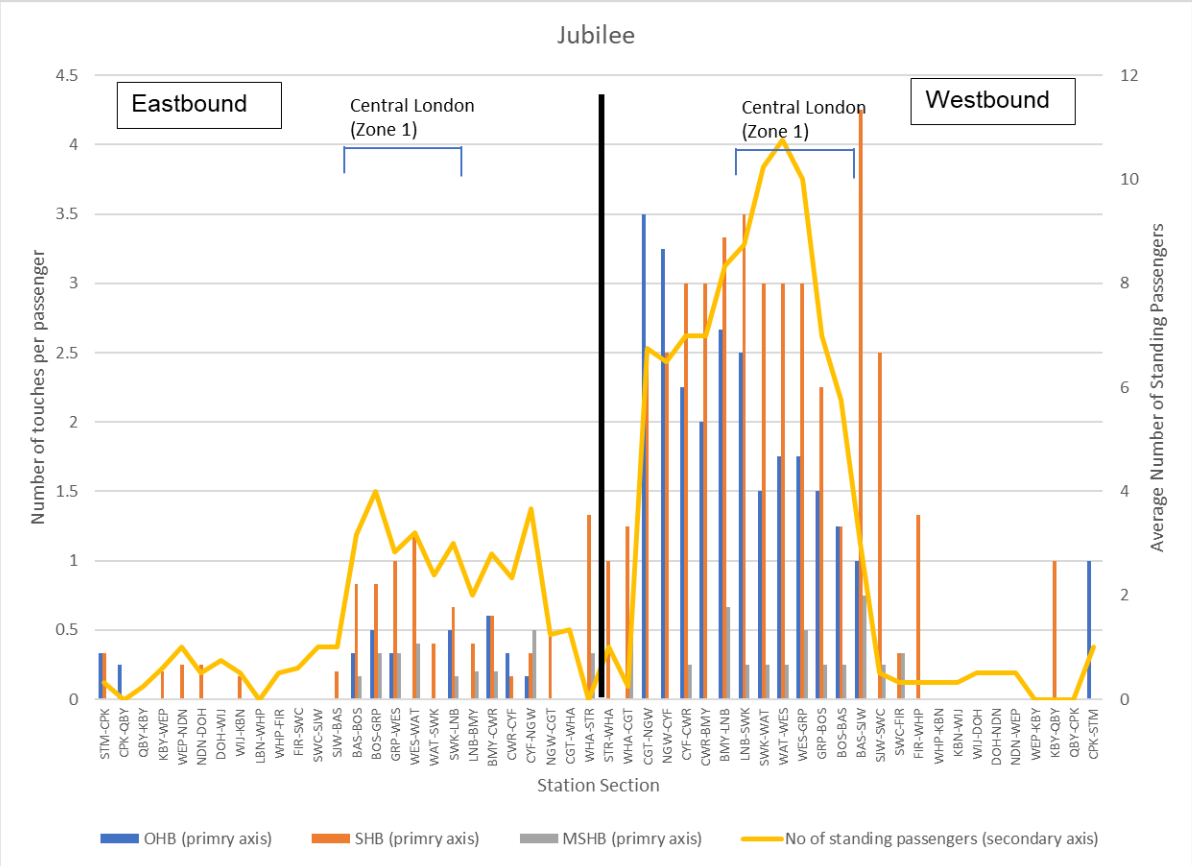


Figure 5. Relationship between the number of touches divided by the number of people and the number of passengers across the station sections for each line. The figures for District line are divided into two as the number of passengers and movements were very different.

4. Discussion

This paper looked at the relationship between passenger numbers and the number of touches to investigate fomite exposure of metro passengers, which can inform how to mitigate fomite infection risk in future global pandemic challenges. A cumulative total of 3803, 2651, and 10527 people were observed at an average of 8.41, 11.89, and 9.22 passengers at each station section (i.e., between two consecutive stations) on Victoria, Jubilee, and District lines respectively. The average number of touches made at each station section ranged from 0.25 to 2.35 depending on the type of facility and the line (Table 2). If we suppose an average running time of two consecutive stations to be 2 minute, then for example a District Line OHB would be touched by 1.12 /2 * 60 = 30.36 times in one hour. This is much higher than touches on hospital furniture (maximum 7.9 according to (Wang et al., 2021)) or restaurants (7.8 according to (N. Zhang, Chen, et al., 2021)) and highlights the risk of penitential fomite infection of public transport vehicles.

It can be noticed that generally District line has different trends (Table 3, Table 4, Figure 4). The sectional area (including the height) of District line vehicles is larger than that for Victoria and Jubilee lines, which may have led to the different results. One of the reasons why passengers grab facilities may be to support balance (so that they don't fall) as existing research on buses suggests that passengers cannot retrain balance without extra support (e.g. grabbing a handrail) when the vehicle is in acceleration(De Graaf & Van

Weperen, 1997). It was observed that passengers on Victoria and Jubilee lines often bent their bodies when they sat down, stood up or leant on door leaves (because of the low ceiling) and this may have contributed to these lines having different results from District line. This difference in facility types between carriage designs garnered different results as well. MSHB had 1.48 and 1.07 touches on average for Victoria and Jubilee lines respectively, which is fewer than OHB or SHB (Table 2, Table 3). It is speculated that, in addition to the quantity of facilities in the vehicle, the location of the handlebars could have affected the number of touches made in crowded situations because it was observed that when crowded, standing passengers in the vestibule area (i.e., the area near to doors) stand close to MSHB, thereby obstructing other people from grabbing it.

Figure 3 suggests that, for Victoria and Jubilee lines, the number of touches increased according to the passenger density after a certain point. Interestingly, Figure 4 suggests that for Victoria and Jubilee lines, there could be potential thresholds for the number of standing passengers (i.e., around 8 to 10 passengers, which is equivalent to 1.5 standing passengers per square meter (3 passengers per square meter if sitting passengers were included) beyond which the numbers of SHB and OHB touches per person increases. It is speculated that a reason for this is the aforementioned passenger balance-taking. Passengers may not want to bump into others, and when the density reaches a certain point where other passengers are near, passengers may engage in more delicate balance-taking manoeuvres, thereby touching train interiors. This can also explain why such a threshold was not clear for District line because of less need to bend (due to the high ceiling) and may have contributed to the lower R^2 value of the univariate regression models (Table 4) because such non-linearity cannot be explained well by linear regression models.

Figure 5 suggests that sections with many standing passengers had great numbers of touches per passenger. Notably, the Westbound sections up to BKS showed great numbers. This corresponds with the finding above that when there were many standing passengers, the numbers of touches per passenger were high and the relationship may be non-linear. There were some sections where great numbers of touches per passenger were observed but this could be because these sections had many boarders and alighters.

As for the implication of this study, first, infection risk models could consider how people touch train interiors. Table 5 provided average values, and because each passenger would make at least two movements (i.e., boarding and alighting), it can be assumed that each person would touch at least twice the numbers provided in the table in his/her journey (and if the journey involves transfer from one line to another, this number should be further multiplied). Note that, as the result suggests, the types of trains would affect how people touch interiors, so these numbers may need to be adjusted according to the train carriage designs. Secondly, train operating companies could consider this in their preparation for potential future pandemics. The results for Victoria and Jubilee lines suggest that for certain types of facilities (SHB, OHB), the number of touches each person makes would increase if the density reached around 1.5 standing passengers per square meter, which is a relatively low value considering that when very crowded the passenger density could reach 5 people per square meter (Luangboriboon et al., 2021). If the infection route of a future pandemic were fomite exposure, the obtained knowledge in this study could be a threshold on the crowding level inside the train carriage.

5. Conclusion

This finding and the obtained average number of touches per passenger movement can be used for preparation for future fomite infection-based pandemics and their risk modelling. It was found that passengers often touch train interior facilities when they board on and alight from a train. The results showed that on average for each type of interior on Victoria and Jubilee lines, there were between 0.07 to 0.57 touches per passenger movement (i.e. boarding or alighting) for deep tube lines, whilst District line that uses larger carriages showed a different tendency. Such touches increased after the number of standing people in the carriage reached a certain point (around 1.5 standing passengers per square meter or 3 passengers per square meter if sitting passengers were included) because they would avoid bumping into others.

Interestingly, these numbers of surface touches may not be proportionate to the journey duration because passengers made most touches when they boarded or alighted, which is in contrast with infection risk of airborne transmission-based infectious diseases which may be proportionate to the duration of close-proximity contacts. This suggests that in future pandemics, infection risk within trains or even public transport vehicles in general can depend on whether they are airborne or surface-borne transmission.

Whilst this study focused on London Underground trains and characterised their passenger touch behaviour, the touch frequency may also depend on the vehicle interiors (e.g. seat layout) as well as types of acceleration (for example, bus vehicles would have higher acceleration (De Graaf & Van Weperen, 1997)), and hence further studies can be conducted on trains with different types of interiors (e.g. intercity services) as well as different types of public transport systems (e.g. buses). In addition, the study did not consider how passengers touch their own faces. An investigation on the correlation between the surface contamination and surface touches in underway (Seo et al., 2023), future research should try to provide evidence of the whole mechanism of potential fomite infection: how bacteria/virus could be passed on from one person to another.

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