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Larger distances from larger vehicles: effect of vehicle size, viewing side and their facia on comfort distance in virtual reality

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ABSTRACT

Objective: It is of critical importance to develop socially sensitive vehicles that will enhance pedestrians' sense of comfort and safety. The current study is the first to extend these effects to vehicles, by investigating individual comfort distance in virtual reality with regard to vehicles that vary in terms of size, viewing angle and anthropomorphized emotional expression. Furthermore, we investigate the effect of individual differences in terms of height, anxiety and aggression.

Method: Forty-four individuals were presented with three-dimensional stimuli of vehicle models differing in size and viewing angle in virtual reality and positioned them at the distance they felt the most comfortable with.

Results: Our results show that individuals are more comfortable standing further from larger vehicles and when presented with the front versus the rear view of a vehicle. Moreover, the distance from vehicles was negatively associated with the height of the individuals.

Conclusion: This paper suggests that it is important for designing self-driving and autonomous vehicles to consider that vehicle size and direction as well as pedestrian's height may impact the comfort distance felt by pedestrians. These data have clear implications for vehicle design, including self-driving and autonomous vehicles.

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Vehicle size; virtual reality; comfort distance; cars and trucks; vehicle perception

KEY POINTS

What is already known:

(1) Individuals maintain larger distances when in front of individuals/agents than beside or behind them.
(2) Individuals provide greater physical space to larger agents (animals and/or humans).
(3) No previous study investigated the effect of vehicle size, view angle, and fascia on the comfort distance preferred by individuals as pedestrians.

What it adds:

(1) Individuals are more comfortable standing further from larger vehicles.
(2) Individuals prefer to place more distance between themselves and a vehicle when seeing it from the front versus the rear.
(3) Shorter individuals adopt a larger distance from vehicles irrespective of vehicle size and viewing side.

Every day people are being killed on roads due to accidents involving vehicles. For example, in 2018 more than 36,500 people were killed in motor vehicle traffic crashes on roadways in the United States (National Center for Statistics and Analysis, 2019). The emergence of self-driving and autonomous vehicles adds even more to the concerns over the safety of the vehicles (Becker & Axhausen, 2017; Shariff et al., 2017) as well as to the responsibility of technology designers (Mladenović et al., 2014). Therefore, the development of socially sensitive vehicles that can interact effectively with humans is of critical importance. Previous research has investigated the relationship between headway (i.e., distance in time or space to the front vehicle) and driver's comfort in automated vehicles (Lewis-Evans et al., 2010; Siebert & Wallis, 2019; De Vos et al., 1997), and has shown contradictory results regarding the effect of vehicle size on headway. For example, while some researchers have reported that drivers will keep shorter distances from trucks compared to cars (Brackstone et al., 2009; Sayer et al., 2003), this is by no means always the case (e.g., Duan et al., 2013).

In addition to what is already studied regarding headway, anything that can be done to enhance pedestrians'

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sense of comfort and safety when encountering vehicles of different shapes and sizes would be beneficial to designers. The present study is one of the first to consider this issue by investigating human comfort distance preferences as a pedestrian for a variety of vehicles. Using immersive Virtual Reality (VR), we investigate this issue with regard to vehicle size, view angle and fascia (i.e., the front area of vehicles including such components as the grille, front bumper and headlamps). The employment of simulators and VR is frequently being used in headway research and driving simulators, with the results providing a reliable estimation of distance compared to real driving experiences (Risto & Martens, 2014). Recognizing that the effect of these variables may vary between individuals, we also assessed how the effect of these factors may be altered by individual differences in height, anxiety and aggression.

Individuals maintain larger distances when in front of individuals/agents than beside or behind them, possibly because forward-facing agents are perceived as more dominant and/or threatening (Amaoka et al., 2009; Bailenson et al., 2003; Hayduk, 1981; Yu & Lee, 2019). Vehicles share similarities to biological agents when viewed from the front because vehicle fascia – features resembling faces – are placed on the front of vehicles (Desmet et al., 2000; Windhager et al., 2008). In particular, individuals attribute similar features such as eyes, mouth and ears to car fasciae (Windhager et al., 2012, 2010, 2008), and viewing car fasciae can produce similar neural activity as viewing human faces (Erk et al., 2002; Gauthier et al., 2000; Kloth et al., 2013; Kühn et al., 2014). In light of these similarities, we hypothesize that individuals will prefer larger distances when viewing a vehicle from the front compared to the side or rear views.

Previous research has shown that individuals provide greater physical space to larger agents (animals and/or humans) as larger body sizes are associated with higher social status, dominance and physical formidability (Ellis, 1994; Parker, 1974; Sell et al., 2012). Similarly, people provide greater distance to taller individuals, both in everyday life (Stulp et al., 2015) as well as in virtual reality environments (Pazhoohi et al., 2019; Ruggiero et al., 2019). Accordingly, we hypothesize that larger vehicles will be provided greater distance than smaller cars. And as vehicle height is relative to an individual's height, we expect that an individual's height will influence their comfort distance from vehicles. This prediction is based on previous reports that individuals prefer larger distances from virtual agents who are taller than themselves (Pazhoohi et al., 2019; Ruggiero et al., 2019).

Individuals also attribute emotional expression to car fasciae (Aggarwal & McGill, 2007; Landwehr et al., 2011; Purucker et al., 2014), and previous research has indicated that people avoid angrier faces and/or provided more physical space to individuals with negative facial expressions (e.g., sadness, anger and disgust) (Cartaud et al., 2018; Ruggiero et al., 2017; Seidel et al., 2010). Therefore, we expect that people will prefer to be further away from vehicles with fasciae that have negative "fascia expressions".

Finally, we looked into individual differences in anxiety and aggression as previous research has shown that the space that individuals prefer to put between themselves and others changes with their anxiety (Iachini et al., 2015; De Vignemont & Iannetti, 2015) and aggressive traits (Curran et al., 1978; Schienle et al., 2017; Walkey & Gilmour, 1984). In keeping with these past empirical studies, we hypothesize that people with a higher score on self-reported anxiety or aggression will prefer larger distances from vehicles.

In sum, to investigate the effects of vehicles' size, view angle and fascia on individual comfort zone, we employed 3D vehicle stimuli differing in size (small vs. large), fascia expression and view orientation (front, side and rear views) in a laboratory setting using a VR environment.

Methods

Participants

Forty-four undergraduate students (36 females) aged between 18 and 30 ($M = 20.54$, SD = 2.71) from the University of British Columbia gave their written consent and participated in this study in exchange for course credit. All participants were verbally instructed by the experimenter during the study, and also verbally indicated that they were unaware of the purpose of the study. As for their highest educational degree, 47.7% had a high school diploma, 6.8% had a post-secondary diploma, and 45.5% had an undergraduate degree.

Stimuli

The three-dimensional stimuli used in this study were composed of 30 vehicle models in VR (20 cars and 10 trucks). Each vehicle was presented at 3 different viewing angles: front, side, and rear views, resulting in 90 trials (see Figure 1 for examples). We also included cylinders with no social valence (Iachini et al., 2014) to acquire a baseline measure of the effect of size. There were two horizontal cylinders, one small and one large, matching the average size of the cars and trucks, respectively, in height and diameter. Each of the

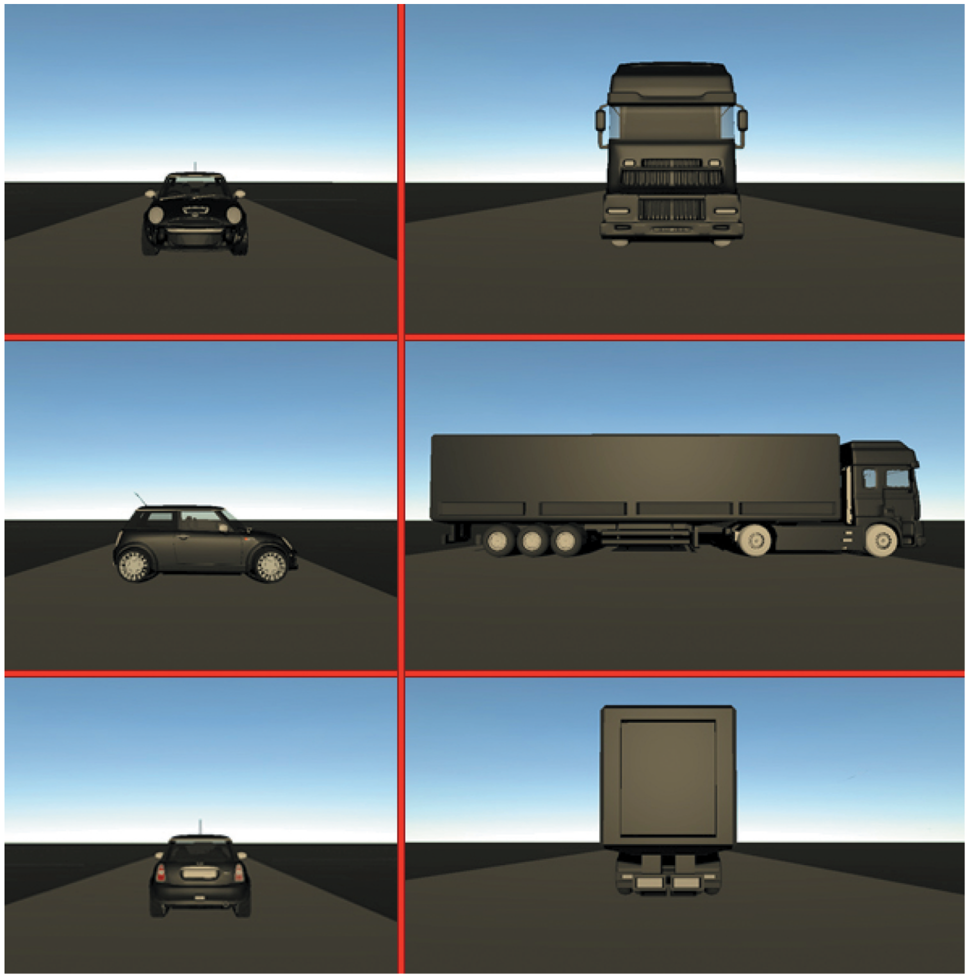

Figure 1. Examples of small and large vehicles in front, side, and rear views presented to participants.

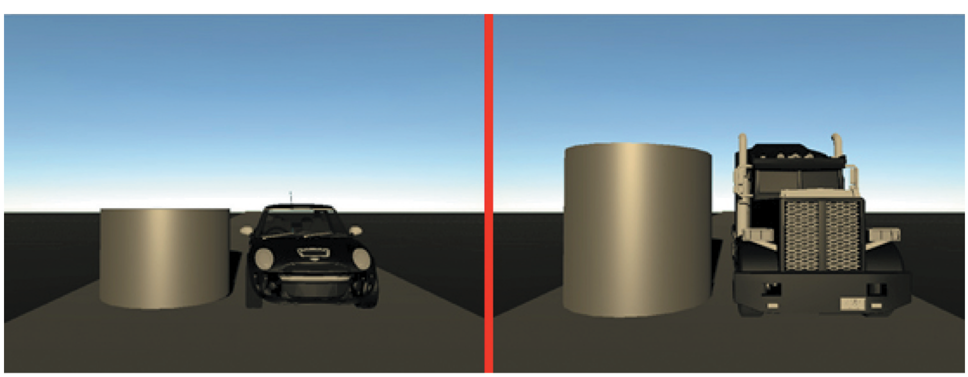

Figure 2. Example of vehicles (small and large) along with the cylinders matching their size. In another study (Pazhoohi & Kingstone, 2020) the left vehicle has been rated the most submissive and feminine, and the right vehicle has been rated most dominant and angry.

cylinders was presented 5 times, making a total of 10 (see Figure 2). This added 10 more trials to our study, making 100 trials in total for each participant. The vehicle model designs were duplicated from real vehicle designs and developed using Unity Real-Time Development Platform (https://unity.com/).

The front view of 27 out of 30 stimuli used in this study was previously rated by a separate set of participants

(N = 221) on a slider scale from −10 to +10 for the perceptions of Submissive/Dominant, Angry/Happy, Masculine/Feminine and Hostile/Friendly (Pazhoohi & Kingstone, 2020).

Materials and procedure

After consenting to take part in the study, participants completed a set of questionnaires: a general demographics' questionnaire (including age, education, marital status and height); the Beck Anxiety Inventory (Beck et al., 1988); and the self-report Aggression Questionnaire (Buss & Perry, 1992).

The study employed the HTC Vive Virtual Reality (VR) System to administer the experimental task. The HTC Vive VR headset screen covers about 110 degrees of field of view (around 90 degrees per eye) with the resolution of 1080 × 1200 pixels per eye (2160 × 1200 pixels combined), and a refresh rate of 90 Hz. All participants were provided with their own VR mask for hygienic purposes. The participants were also asked to use the accompanying HTC Vive controllers to complete the comfort distance task. The HTC Vive controllers feature 24 sensors, multi-function trackpad, dual-stage trigger, HD haptic feedback and a rechargeable battery. Participants were asked to use only the dual-stage trigger, and the two side buttons on the controller. Participants were familiarized with the HTC Vive VR System before the onset of the 100 trials. This involved the experimenter explaining the VR system, verbal instructing participants on how to use the controller, and illustrating the task on an Acer LCD Monitor before they enter the VR environment. Once inside the VR participants were encouraged to use the controller to vary the distance between themselves and the object that they were facing, selecting to move onto the next trial once they felt that the object they were viewing was positioned at the distance they felt the most comfortable with. In other words, participants had to minimize their distance from the vehicles to the point they would not feel comfortable anymore if the vehicle/object would come further closer. The vehicles were stationary during the evaluation. All participants completed the 100 trials in random order.

Results

Vehicles vs. Cylinders

First, we tested the effect of object size on comfort distance by comparing the distance between small and large vehicles and cylinders. As there was no equivalent for front and rear views in the cylinders, each of the three vehicle views were examined separately with vehicle size compared against its cylinder match. Therefore, a total of three linear mixed models (one for each view) were conducted to test the effect of object size (four groups: small and large vehicles, and small and large control cylinders) on comfort distance. In the frontal view, there was a significant effect of size, $F(3,43.6) = 32.6$, $p < .001$. Post hoc comparisons indicated that comfort distance from the large cylinder (M = 16.3, SE = 1.33) and large vehicles (M = 16.6, SE = 1.08) were greater than both the small cylinder (M = 11.5, SE = 1.06) and small vehicles (M = 11.4, SE = 0.84, all $ps < .001$, Figure 3(a)). There were

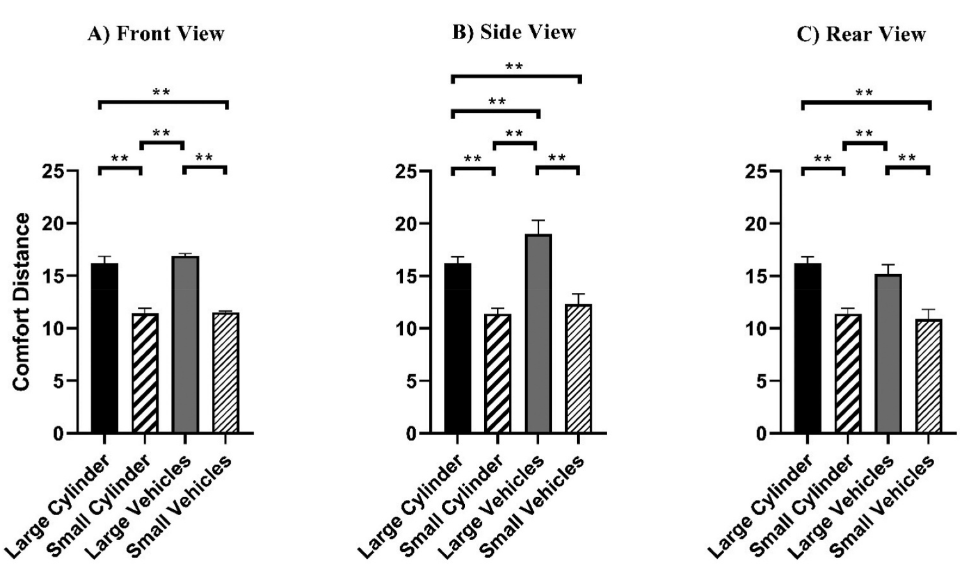

Figure 3. Means and SEM for comfort distance from vehicles and cylinders as a function of size, for (a) front, (b) side and (c) rear views. ** $p < .001$.

no differences between a large cylinder and large vehicles or a small cylinder and small vehicles (*ps* > .996). For the side view, the effect of size was significant ($F(3,62.2) = 39.3$, $p < .001$). Post hoc comparisons showed that comfort distance from the large cylinder and large vehicles ($M = 19.0$, SE = 1.30) were greater than the small cylinder and small vehicles ($M = 12.3$, SE = 1.00, all $ps < .001$, Figure 3(b)). While there was no difference between small vehicles and a small cylinder in comfort distance, participants preferred significantly greater distance between large vehicles compared to a large cylinder ($p = .001$). Results for rearview showed a significant effect of size ($F(3,56.6) = 27.6$, $p < .001$), with greater distances from a large cylinder and large vehicles ($M = 15.2$, SE = 0.90) than both the small cylinder and small vehicles ($M = 10.9$, SE = 0.63, all $ps < .001$, Figure 3(c)). There were no differences between a large cylinder and large vehicles or a small cylinder and small vehicles (*ps* > .998).

Vehicle size and view

A 2 (Vehicle Size: small vs. large) × 3 (Vehicle View: front, side and rear) repeated measures analysis of variance (ANOVA) with Participants as a random factor tested the effect of vehicle size and vehicle view on comfort distance. Results indicated a significant main effect of Vehicle Size, $F(1,43) = 78.76$, $p < .001$, partial $\eta^2 = 0.64$. As expected, participants chose a larger comfort distance from large vehicles ($M = 16.94$, SD = 0.10) than small vehicles ($M = 11.51$ m, SEM = 0.08). There was also a significant main effect of Vehicle View, $F(2,86) = 11.18$, $p < .001$, partial $\eta^2 = 0.20$. Participants chose a significantly larger comfort distance for side views ($M = 15.61$ m, SEM = 0.11) than front (M = 14.03 m, SEM = 0.11, $p < .001$) and rear views ($M = 13.03$ m, SEM = 0.11, $p < .001$). They also selected a larger distance for front than rear views ($p < .001$). The two main effects, size and view, were qualified by a significant Size × View interaction, $F(2,86) = 15.42$, $p < .001$, partial $\eta^2 = 0.26$. For all viewing angles, the comfort distance was larger for large vehicles compared to small ones (all $ps < .001$); and the comfort distance for side views was larger than front and rear views for both vehicles' size categories (all $ps < .011$; see Table 1 for means and SEMs and Figure 4).

Participants' height

Results of a correlational analysis showed negative correlations between participants' height and comfort distance as a function of vehicle size and view (Table 2), suggesting shorter individuals made larger comfort

Table 1. Mean and SEM for comfort distance from vehicles as a function of size and view.

				95% Confidence Interval	
Vehicle Size	Vehicle View	Mean	Std. Error	Lower Bound	Upper Bound
Small	Front	11.43	0.14	11.15	11.70
	Side	12.26	0.14	11.99	12.53
	Rear	10.85	0.14	10.58	11.13
Large	Front	16.65	0.18	16.29	17.01
	Side	18.96	0.18	18.60	19.32
	Rear	15.22	0.18	14.86	15.58

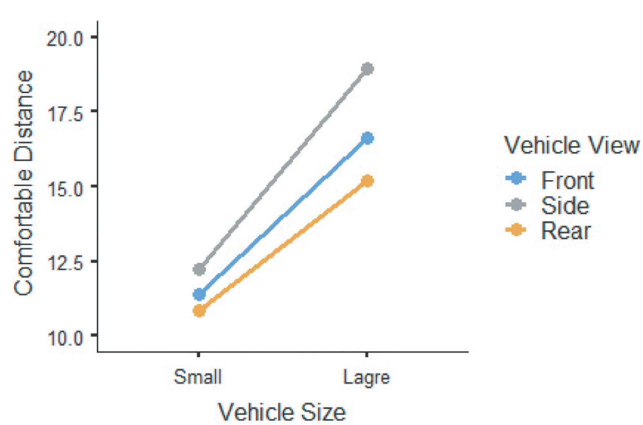

Figure 4. Mean for comfort distance from vehicles as a function of vehicle size and their view.

Table 2. Pearson's correlation coefficient (r) for correlation analysis between participants' height and the comfort distance for each categoriy of objects ($N = 44$).

Vehicle Size	Vehicle View	r	p
Small	Front	−0.41**	.006
	Side	−0.39**	.009
	Rear	−0.32*	.031
Large	Front	−0.52**	.001
	Side	−0.49**	.001
	Rear	−0.43**	.003
Small Cylinder		−0.17	.251
Large Cylinder		−0.16	.298

* $p < .05$, ** $p < .01$

distances from the vehicles regardless of the vehicle size or view angle. The relationship between the height and distance from the cylinders was not significant.

Individual differences

Results of the correlational analysis did not return any significant relationship between self-reported measures of anxiety or aggression and comfort distance for stimulus size or vehicle view angle (all *ps* > .116). Furthermore, we compared the comfort distance for those of participants with M + 1 SD vs. M – 1 SD on self-reported measures of anxiety or aggression, and no significant difference were observed.

Dominance, masculinity and emotion

The correlational analysis returned significant relationships between comfort distance (in front views) and the vehicles' perceived dominance ($r(25) = .74$, $p < .001$, $n = 27$), anger ($r(25) = .86$, $p < .001$), masculinity ($r(25) = .81$, $p < .001$) and hostility ($r(25) = .83$, $p < .001$). Specifically, participants provided greater distance to more dominant, masculine, hostile, and angry vehicles. However, when using partial correlations to control for vehicle size, the relationships were not significant (all *ps* > .262), suggesting that comfort distance is primarily a factor of a vehicle's size rather than being influenced by the different emotional valence of its fascia.

Discussion

This is the first study to investigate the effect of vehicle size, view angle, and fascia on the comfort distance preferred by individuals as pedestrians. We also considered individual differences in terms of anxiety, anger, and height on preferred comfort distance.

The results of our study showed that individuals prefer a larger distance for larger objects, as participants reported larger comfort distances for large vehicles and large cylinders than small vehicles and cylinders. This effect was the same whether the object was a cylinder or a vehicle (Figure 1). However, when we included a vehicle's view angle into the analysis, the data revealed that participants made significantly larger comfort distances for side views than front and rear views, for both small and large vehicles. They also preferred a larger distance for front vehicle views than rear views for both vehicle categories.

The large comfort distance for side views could reflect participants' need for a larger distance in order to bring the full width of the vehicle into view. However, this account does not appear to explain our finding that participants placed more space between themselves and the vehicles when posed with a front view versus a rearview, as the width and height were the same for both views. While our observation that perceived dominance, anger, masculinity and hostility from vehicles' fasciae do not modulate the front view comfort distance; our finding that comfort distance is greater for front than rear views aligns with past investigations indicating that individuals are less comfortable when posed with frontward facing than rearward-facing individuals/agents (Amaoka et al., 2009; Bailenson et al., 2003; Hayduk, 1981; Yu & Lee, 2019). Thus, one explanation is that it appears that individuals attribute agency characteristics to front versus rear-facing vehicles even though this significant effect is not modulated by the negative expression of a vehicle's front fascia. It may also be the case that individuals attribute agency to the putative drivers of the vehicles (or some combination of vehicles and drivers), hence the larger distance when posed with front versus rear facing vehicles.

Regarding individual differences, while the self-reported measures of anxiety or aggression did not influence individuals' comfort distances from the vehicles, individuals' height was negatively associated with the preferred comfort distance, indicating shorter individuals adopted a larger distance from vehicles irrespective of their size and viewing side. Interestingly, no specific pattern was observed between height and cylinders. These data suggest again that participants associate agency to the vehicles (Windhager et al., 2008) as previous research has shown that individuals distance themselves differently from anthropomorphic agents versus nonbiological objects such as cylinders (Iachini et al., 2014). Specifically, individuals prefer to keep a larger distance from larger/taller agents (such as humans) and also that the distance increases for shorter individuals than taller ones (Pazhoohi et al., 2019; Ruggiero et al., 2019; Stulp et al., 2015). It should be noted that the majority of the individuals who participated in the study were undergraduate women and due to the preponderance of female participants in this study, sex differences were not analysed. The disproportionately high number of female participants reflects the enrolment ratio for psychology at the University of British Columbia, and therefore future investigations should consider possible sex differences in this regard. Specifically, the higher number of female participants in our study might has had a confounding effect on our results as it is known that men are on average taller than women, and therefore, a comparable study that includes more male participants seems warranted.

In sum, the present study examined the effects of vehicle size, view and fascia on participants' comfort distance as pedestrians. We also considered individual differences in anxiety, aggression, and height. Collectively the results reveal that individuals are more comfortable standing further from larger vehicles, and they prefer to place more distance between themselves and a vehicle when seeing it from the front versus the rear. These effects are accentuated for shorter individuals. Our results also indicate that individuals attribute agency to vehicles as evidenced by the fact that these key effects are divergent from, or absent, for neutral baseline objects (i.e., cylinders). Finally, one of the implications of our study concerns self-driving and autonomous vehicle designs, as they highlight how important it is to consider that vehicle size and direction – front (approaching) vs. rear (reversing) – may impact the comfort distance felt by pedestrians' of different heights. For example, in pedestrian crossing situations large vehicles should be made to stop further from the pedestrian crossing the road to increase their sense of safety. There are several other implications for designers of automated vehicles as it pertains to interactions with pedestrians. It is known that in VR pedestrian crossing scenarios, vehicle characteristics such as vehicle type, emitted sound, and pattern of movement, can influence how people react to an approaching vehicle (Simpson et al., 2003; Soares et al., 2020). Accordingly, designers might consider the interactions between vehicle size, type, colour and fascia on the comfort distance of the pedestrians and make the most threatening combination stop at larger distances from pedestrians.

Disclosure statement

No potential conflict of interest was reported by the authors.

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