

22 **Abstract**

23 Differently sized automated vehicles (AVs) will enter the roads of tomorrow and will
24 interact with other road users. Pedestrians as vulnerable road users heavily rely on the
25 communication with other road users, especially for the interaction with larger vehicles, as
26 miscommunication pose a high risk. Therefore, AVs need to provide communication abilities
27 to safely interact with pedestrians. This study's focus was on the explicit communication which
28 is highly relevant in low-speed and low-distance traffic scenarios to clarify misunderstandings
29 before they result in accidents. External human-machine interfaces (eHMIs) placed on the
30 outside of AVs can be used as a communication tool to explicitly inform the surrounding traffic
31 environment. Although research manifested effects of vehicle size on pedestrians' perceived
32 safety and crossing behavior, little research about the eHMI design for differently sized AVs
33 exists. This experimental online study ($N = 155$) aimed at investigating the application of a
34 light-based eHMI on two differently sized AVs (car, bus) by focusing on the overall goal of
35 ensuring traffic safety in future traffic. The light-based eHMI showed different communication
36 strategies, i.e., a static eHMI and three dynamic eHMIs. The results revealed that an automated
37 car was perceived as safer and affectively rated as more positive compared to an automated bus.
38 Nevertheless, no significant differences were found between the two AVs in terms of the eHMI
39 communication. A dynamic eHMI was perceived as safer and evaluated affectively as more
40 positive compared to a static eHMI or no eHMI for both AVs. In conclusion, the use of a light-
41 based eHMI had a positive effect on pedestrians' interaction with an automated car and an
42 automated bus and, therefore, could contribute to the overall traffic safety in this study.
43 Implications for the design of eHMIs for differently sized AVs were discussed.

44 **Keywords:** external human-machine interface; vulnerable road users; pedestrians;
45 automated vehicles; vehicle size

47 **1 Introduction**

48 Interaction in urban traffic can be described as a complex and dynamical process, in
49 which differently sized vehicles interact with other traffic participants (TPs), e.g., pedestrians
50 and cyclists (Schieben et al., 2019a). This interaction will change with the implementation of
51 AVs on roads to the extent that other TPs will no longer directly communicate with human
52 drivers. The vehicle automation will take over more and more control and, therefore, the
53 interaction with other TPs and previously used communication methods will change (Li, Cheng,
54 Zeng, Liu, & Sester, 2021; Merat, Louw, Madigan, Wilbrink, & Schieben, 2018; SAE
55 International, 2021). This change may come at risk especially for pedestrians who depend on
56 the communication with other TPs, in particular, in low-distance and low-speed scenarios, e.g.,
57 shared spaces (Li et al., 2021). Due to their high vulnerability, miscommunication can pose a
58 risk for pedestrians, especially in the interaction with larger sized vehicles (Fuest, Sorokin,
59 Bellem, & Bengler, 2017; Schaarschmidt et al., 2021). Therefore, it needs communication tools
60 for AVs to avoid miscommunication and prevent accidents between AVs and pedestrians
61 (Ackermann, Beggiato, Schubert, & Krems, 2019; Habibovic et al., 2018; Schieben et al.,
62 2019b).

63 External human-machine interfaces (eHMIs) enable explicit communication with other
64 TPs, e.g., via light signals (Faas, Mathis, & Baumann, 2020; Schieben et al., 2019a; Schieben
65 et al., 2019b). Explicit communication signals are directly sent to the pedestrian and provide
66 clear information about the vehicle's (future) behavior, e.g., turn indicators (Färber, 2016;
67 Markkula et al., 2020). Overall, current studies revealed that eHMIs can positively impact the
68 interaction with pedestrians in terms of perceived safety and the overall emotional state of
69 pedestrians (Clercq, Dietrich, Nuñez Velasco, Winter, & Happee, 2019; Habibovic et al., 2018;
70 Habibovic et al., 2019; Schieben et al., 2019a). However, most of these studies applied the
71 eHMI only on one vehicle size and only little research focused on the design of eHMI

72 communication strategies for larger vehicles (Dey et al., 2020b). Therefore, this study focused
73 on the investigation of different eHMI communication strategies that differed in their
74 information richness for the interaction between pedestrians and two differently sized AVs on
75 a shared space to ensure an overall well-working interaction.

76 **1.1 Today's interaction in urban traffic**

77 Today's urban traffic consists of several interactions in which the other's intention must
78 be understood to be able to derive one's own decisions from it (Ezzati Amini, Katrakazas, &
79 Antoniou, 2019). For a safe and efficient interaction, clear and efficient communication among
80 TPs is needed to solve ambiguities and misunderstandings before they end in safety-critical
81 traffic situations (Ezzati Amini et al., 2019; Lehsing, Fleischer, & Bengler, 2016). In particular,
82 pedestrians rely heavily on communication signals when interacting with human drivers due to
83 their larger risk of getting injured (Habibovic et al., 2018; Rasouli & Tsotsos, 2020).

84 Generally, human drivers use implicit and explicit communication signals to
85 communicate with pedestrians every day (Bengler, Rettenmaier, Fritz, & Feierle, 2020; Ezzati
86 Amini et al., 2019). In contrast to explicit signals, implicit communication signals are not
87 directly addressed to pedestrians, but can be used to extract information, e.g., vehicle
88 deceleration or acceleration (Bengler et al., 2020; Dietrich et al., 2018). For example, drivers
89 communicate the intent, to let the pedestrian cross, by initially decelerating the vehicle. The
90 deceleration helps pedestrians to anticipate the vehicle's future actions (Ezzati Amini et al.,
91 2019). Explicit communication signals are directly addressed, e.g., drivers use eye contact or
92 hand gestures to show pedestrians that they can cross (Stanciu et al., 2018). The use of implicit
93 and explicit communication of road users in today's traffic was investigated for traffic
94 scenarios, e.g., with a speed limit of 50 km/h (31.06 mph) and low-speed areas (Habibovic et
95 al., 2018; Lee et al., 2020; Schieben et al., 2019b; Schneemann & Gohl, 2016). Studies revealed
96 that implicit communication stood as a primary indicator for pedestrians' crossing decisions

97 especially in higher speeds (Dey et al., 2020a; Dey & Terken, 2017; Lee et al., 2020; Rasouli
98 & Tsotsos, 2020). In contrast, explicit communication was highly relevant in low-speed areas
99 when pedestrians and drivers stood in close distance (Dey et al., 2020a; Habibovic et al., 2018;
100 Lee et al., 2020; Schneemann & Gohl, 2016). However, Sucha et al. (2017) showed that 84%
101 of the pedestrians searched for eye contact with the drivers. Moreover, explicit communication
102 helped to solve traffic situations when misunderstandings occurred and/or negotiation was
103 needed, e.g., when the vehicle showed unexpected behavior (Dey et al., 2020a; Dey & Terken,
104 2017; Habibovic et al., 2018; Lee et al., 2020).

105 In conclusion, pedestrians needed explicit communication to clarify misunderstandings
106 particularly in traffic situations with low distance and low speed. However, this needs further
107 investigation for future interaction in mixed urban traffic and, furthermore, in terms of different
108 low-speed and low-distance traffic scenarios, e.g., shared spaces (Li et al., 2021).

109 **1.2 Future interaction in urban traffic**

110 The introduction of AVs will create mixed traffic environments, as AVs will coexist
111 with other TPs, e.g., manually-driven vehicles and vulnerable road users such as pedestrians
112 (Habibovic et al., 2018; SAE International, 2021; Schieben et al., 2019a; Stanciu et al., 2018).
113 Some traffic situations may be resolved efficiently with AVs; some traffic situations will
114 present challenges (Habibovic et al., 2018). One challenge is the interaction with pedestrians in
115 low-speed and low-distance traffic situations in which, e.g., misunderstandings can occur or
116 negotiation is needed (Dey et al., 2020b; Habibovic et al., 2018; Merat et al., 2018; Schieben et
117 al., 2019a). To face this challenge, AVs need to be able to communicate with pedestrians
118 (Färber, 2016; Habibovic et al., 2018; Schieben et al., 2019a). At this point, AVs do not have
119 the full capacity to replicate the behavior of a human driver (SAE International, 2021), e.g., to
120 read or anticipate from pedestrians' behavior (Parkin, Clark, Clayton, Ricci, & Parkthurst,
121 2016; Stanciu et al., 2018). The question arises what pedestrians' information needs are and

122 how they should be considered for the design of AVs to guarantee an overall safe interaction
123 (Merat et al., 2018).

124 Contrasting results exist on pedestrians' information needs for the interaction with AVs
125 (Habibovic et al., 2018): On the one hand, pedestrians wanted to have additional information
126 only if AV acted carelessly and unexpectedly (Rothenbacher, Li, Sirkin, Mok, & Ju, 2015). In
127 all other interactions, pedestrians stayed with already today's existing behavioral patterns
128 interacting with vehicles (Rothenbacher et al., 2015). On the other hand, studies showed that
129 pedestrians wanted to receive additional information in general, e.g., about the vehicle's
130 automation status (VAS) (Habibovic et al., 2018; Habibovic, Andersson, Nilsson, Lundgren, &
131 Nilsson, 2016; Lundgren et al., 2017), vehicle's intention (Faas et al., 2020; Habibovic et al.,
132 2016; Habibovic et al., 2018; Lundgren et al., 2017; Mahadevan, Somanath, & Sharlin, 2018),
133 and about the vehicle's detection of pedestrians (Merat et al., 2018; Schieben et al., 2020). The
134 trend is towards providing information about the vehicle's intention or combining it with other
135 additional information (Dey et al., 2020b). The presented amount of information can be defined
136 as *information richness* (Wilbrink, Lau, Illgner, Schieben, & Oehl, 2021). For example, the
137 presentation of the VAS and additional information by the AV displays a high information
138 richness (Wilbrink et al., 2021). Current research has shown that a high information richness
139 lead to a higher perceived safety (Faas et al., 2020), a higher feeling of comfort (Clamann,
140 Aubert, & Cummings, 2017), earlier crossing decisions (Wilbrink et al., 2021), and reduced
141 misinterpretations (Merat et al., 2018) Therefore, it seems important to present a high
142 information richness to inform pedestrians sufficiently and, thus, to enable a safe interaction
143 with AVs.

144 Overall, the interaction between pedestrians and vehicles will change with the
145 introduction of AVs to the point that no human driver will exist for explicit communication.
146 Nevertheless, AVs need to communicate with pedestrians explicitly to avoid

147 miscommunication. To integrate AVs into future traffic safely, current research showed that
148 pedestrians required a high information richness, i.e., information about the VAS and additional
149 information about the vehicle's intention. However, the challenge is to define an adequate level
150 of information richness that is required by pedestrians to feel safe and comfortable, in particular,
151 in the interaction with larger sized AVs. Focusing on how to present these explicit
152 communication signals for AVs, eHMIs work as communication mean between AVs and
153 pedestrians (Dey et al., 2020a; Schieben et al., 2019b).

154 **1.3 Design of eHMIs**

155 An eHMI is a communication mean that is placed on the AV's outside. It is perceptible
156 for interacting with other TPs and transmits explicit information (Bengler et al., 2020; Schieben
157 et al., 2020). This includes information about the vehicle's intentions and future behavior
158 (Habibovic et al., 2019; Schieben et al., 2019a). The overall goal is to design eHMIs that
159 communicate clearly with other TPs in mixed traffic environments (Dey et al., 2020b). Several
160 eHMI design approaches have been developed, e.g., icon-based, text-based, and light-based
161 eHMIs (Bazilinsky, Dodou, & Winter, 2019; Dey et al., 2020b). As the most promising
162 approach, light-based eHMI designs were able to transmit explicit communication signals to
163 other TPs based on different light patterns in a safe and efficient way (Dey et al., 2020a;
164 Mahadevan et al., 2018; Schieben et al., 2019b; Schieben et al., 2020). Previous studies showed
165 that the eHMI should be positioned under the windshield as pedestrians turned their gaze
166 towards this area to seek eye-contact (Dey, Walker, Martens & Terken, 2019). Light-based
167 eHMIs should be easy to understand, because the TPs will most likely interact with eHMIs for
168 the first time (Clercq et al., 2019). A virtual reality study by Avsar et al. (2021) showed that
169 most participants understood the messages of a LED light-based eHMI shortly after their first
170 interaction. Eighty-five percent of the participants fully comprehended the message after two
171 interactions (Avsar et al., 2021). Different studies investigated the effect of light-based eHMIs
172 for the interaction in close distance between pedestrians and an AV in various traffic scenarios,

173 e.g., zebra crossing (Habibovic et al., 2018; Lee, Daimon, & Kitazaki, 2021), parking spaces
174 (Habibovic et al., 2018; Kettwich, Dodiya, Wilbrink, & Schieben, 2019; Schieben et al., 2019a;
175 Schieben et al., 2019b), and non-signalized street crossings (Dey et al., 2020a; Dey, Martens,
176 Eggen, & Terken, 2017; Holländer, Wintersberger, & Butz, 2019; Kaleefathullah et al., 2020;
177 Schieben et al., 2019b). All studies came to the same conclusion that pedestrians felt safer and
178 perceived a more positive experience with an AV equipped with an eHMI compared to no
179 eHMI. However, none of these studies have focused on a shared space scenario as an example
180 of a low-speed and low-distance traffic scenario. A shared space represents a traffic-calmed
181 area which does not include clear traffic rules and is more based on the principle of mutual
182 understanding for each other (Monderman, Clarke, & Baillie, 2006). Thus, the evaluation of
183 eHMIs on a shared space needs further investigation as the external communication is
184 particularly important in those low-speed and low-distance traffic areas (Li et al., 2021).

185 Focusing on the level of information richness of eHMI communication, Wilbrink et al.
186 (2021) compared different levels of information richness on a LED light-band eHMI, i.e., a
187 static eHMI that presents only the VAS with three different dynamic eHMIs (VAS + vehicle's
188 intention, VAS + vehicle's perception, VAS + intention + perception) for pedestrians'
189 interaction with an AV at a non-signalized street crossing. The *dynamic eHMI* is defined as
190 eHMI that presented a higher information richness level compared to no eHMI or a static eHMI
191 as it consisted of additional information, e.g., about the vehicle's intention, the vehicle's
192 perception or both combined (Schieben et al., 2020; Wilbrink et al., 2021). The results showed
193 that the participants felt safer and indicated a more positive affective evaluation, i.e., affective
194 valence, affective arousal, and affective dominance, when the AV presented a dynamic eHMI
195 compared to a static or no eHMI. No significant differences were found between the three
196 dynamic eHMIs. However, the participants rated the usability as "high" for all three dynamic
197 eHMIs (Wilbrink et al., 2021). The findings of this study stand in line with Schieben et al.
198 (2019b), who also did not find differences between dynamic eHMIs for a parking scenario. In

199 contrast, Faas et al. (2020) pointed out that a dynamic light-based eHMI presenting the vehicle's
200 perception did not add value to the overall traffic flow. Instead, presenting the vehicle's
201 intention via a dynamic eHMI was preferred by the participants as additional information over
202 no eHMI. Overall, research showed that a dynamic eHMI increased pedestrians' perceived
203 safety and affective evaluation compared to a static eHMI or no eHMI (Wilbrink et al., 2021).
204 However, there is no clear consensus on which information should be presented on a dynamic
205 eHMI, i.e., vehicle's intention, vehicle's perception or both combined. Moreover, eHMI studies
206 focused primarily on the interaction between pedestrians and an automated car in parking
207 scenarios (Wilbrink et al., 2021; Schieben et al., 2019b) and non-signalized traffic scenarios
208 (Faas et al., 2020). Therefore, these studies lack the consideration of pedestrians' interaction
209 with differently sized AVs and different low-speed and low-distance traffic scenarios, e.g.
210 shared spaces.

211 In conclusion, a dynamic eHMI led to a higher level of perceived safety and a more
212 positive affective evaluation in previous research compared to a static eHMI or no eHMI.
213 However, contrasting results exist on what pedestrians would like to receive as additional
214 information in terms of a dynamic eHMI, e.g., vehicle's intention and/or perception. Moreover,
215 none of these studies have addressed a shared space scenario as an example of a low-speed
216 traffic scenario. Additionally, the vast majority of current eHMI research has focused on only
217 one vehicle size, e.g., a car (Dey et al., 2020b). To this point, no statement can be made about
218 the transferability of eHMI communication strategies on differently sized AVs. Besides that,
219 eHMI communication strategies have not been sufficiently studied for the use case shared
220 space. Therefore, the effect of vehicle size for the interaction between AVs and pedestrians on
221 a shared space was further investigated here.

222 **1.4 Vehicle size**

223 Pedestrians' expectations and actions can differ for differently sized vehicles (Beggiato,
224 Witzlack, & Krems, 2017; Caird & Hancock, 1994; DeLucia, 2013; Petzoldt, 2016). In general,
225 two contrasting cognitive phenomena may explain why pedestrians tend to behave differently
226 when interacting with differently sized, in this case manually-driven, vehicles (Beggiato et al.,
227 2017; DeLucia, 2013; Petzoldt, Ngoc, & Bogda, 2017). On the one hand, the size arrival effect
228 describes that larger objects are perceived to arrive earlier compared to smaller objects which
229 results in more conservative decisions for larger objects (DeLucia, 2013). For example, Caird
230 and Hancock (1994) conducted a study in which the participants had to push a button to indicate
231 when the vehicle arrived at them. The results showed that the participants interacted more
232 carefully and showed more conservative decision times for larger vehicles compared to smaller
233 vehicles (Caird & Hancock, 1994). On the other hand, the size-speed bias describes that larger
234 objects are perceived as slower as smaller objects, which can result in more riskier crossing
235 decisions (Leibowitz, 1985). Clark, Perrone, and Isler (2013) investigated the effect of different,
236 manually-driven vehicles on human speed perception and results showed that a train, as a larger
237 vehicle, is perceived as equally fast as a car, although the train moved up to 13km/h (8.08 mph)
238 faster. Petzoldt et al. (2016) investigated the effect of vehicle size on the judgments of a
239 vehicle's speed and time-to-arrival. His results confirmed the assumption of a size-speed bias
240 effect, but did not support the size-arrival effect. In conclusion, these studies focused on
241 objective measurements to investigate the effect of differently sized vehicles on pedestrians'
242 perception and decision. To this point, the effect of vehicle size on pedestrians' perception has
243 been not sufficiently investigated based on subjective measurements, e.g., the perceived safety
244 or the affective evaluation. Moreover, most studies focused on the interaction between
245 manually-driven vehicles and pedestrians. It needs further research on the effect of vehicle size
246 needs to address the future interaction between pedestrians and differently sized AVs.

247 In light of the aforementioned relevance of vehicle size, it is surprising that only little
248 research is available about the pedestrians' interaction with differently sized AVs and,
249 accordingly, the design of eHMIs. As one of the few studies, Dey et al. (2017) compared two
250 differently sized AVs (Renault Twizy, BMW 3 series sedan) and showed that the participants
251 felt safer with a smaller AV (Renault Twizy) compared to the larger AV (BMW 3 series Sedan).
252 Moreover, the participants were more likely to cross the street in front of a small vehicle
253 compared to a larger vehicle and reported that this was due to a greater chance to get out of the
254 way (Dey et al., 2017). Moreover, pedestrians reported to have greater concerns of being hurt
255 when interacting with larger vehicles (Dey et al., 2017).

256 All in all, studies showed that the vehicle size can affect pedestrians' perception in a
257 traffic situation in terms of objective measurements, e.g., time-to-arrival. However, these
258 studies lacked subjective measurements, e.g., pedestrians' perceived safety or affective
259 evaluation of differently sized vehicles. For a safe introduction of AVs, it is essential to focus
260 on pedestrians' subjective evaluation of differently sized AVs in an early stage to derive well-
261 working eHMI designs for different vehicle sizes. Additionally, it needs further consideration
262 of pedestrians' future interaction with differently sized AVs on shared spaces as here mutual
263 understanding is highly required.

264 **1.5 Research aims and hypotheses**

265 This study set three main research aims. Firstly, this study aimed to investigate the effect
266 of vehicle size for pedestrians' interaction with two differently sized AVs on a shared space.
267 Secondly, this study aimed to investigate the effect of different information richness levels of
268 eHMI communication for pedestrians' interaction with two differently sized AVs on a shared
269 space. Thirdly, to build up on this, this study aimed to investigate the effect of three dynamic
270 eHMIs that presented, additionally to the VAS, further information (vehicle's intention vs. the
271 vehicle's perception vs. vehicle's intention + vehicle's perception) for pedestrians' interaction

272 with two differently sized vehicles. Very preliminary results of this study have been already
273 published (Lau, Le, & Oehl, 2021). The following hypotheses were derived focusing on the
274 effect of vehicle size (V1) in Hypothesis 1, the effect of information richness of eHMI
275 communication (V2) in Hypothesis 2 and 2.1. and the effect of dynamic eHMIs (V2) in
276 Hypothesis 3.

277 In today's traffic, pedestrians perceived a higher risk of getting injured by a smaller
278 vehicle compared to a larger vehicle (Beggiato et al., 2017; Caird & Hancock, 1994; DeLucia,
279 2013; Petzoldt, 2016). Regarding future traffic, it has been found that pedestrians perceived a
280 larger AV as less safe compared to a smaller AV affected in a non-signalized crossing traffic
281 scenario (Dey et al., 2017). Thus, it is hypothesized that pedestrians evaluated their interaction
282 with a smaller AV differently compared to a larger AV for pedestrians' interaction on a shared
283 space in this study.

284 **Hypothesis 1 (H1).** A smaller AV is perceived as safer and is evaluated with a more
285 positive affective evaluation, i.e., affective valence, arousal and dominance, and a higher
286 perceived information quality compared to a larger AV (vehicle size; V1).

287 In general, the presentation of an eHMI is perceived as beneficial and helped to resolve
288 ambiguities particularly in low-speed and low-distance areas (Dey et al., 2020a; Faas et al.,
289 2020; Lee et al., 2020; Schieben et al., 2019b). Moreover, pedestrians preferred a high
290 information richness level of eHMI communication, i.e., a dynamic eHMI, over a static eHMI
291 or no eHMI at all (Wilbrink et al., 2021; Faas et al., 2020). From this, the following hypothesis
292 is derived:

293 **Hypothesis 2 (H2).** A dynamic eHMI that presented a high level of information richness
294 lead to a higher perceived safety, a more positive affective evaluation, i.e., affective valence,
295 arousal and dominance, a higher perceived information quality and a higher usability compared

296 to a static eHMI presenting only the VAS or no eHMI (information richness of eHMI
297 communication; V2).

298 Previous studies revealed that a larger vehicle was perceived as more threatening
299 compared to a smaller vehicle (Petzoldt, 2016). This was found also for pedestrians' interaction
300 with larger AVs compared to smaller AVs (Dey et al., 2017). Therefore, we assumed that
301 pedestrians required a higher information richness level by the eHMI for their interaction with
302 the bus compared to a car to feel safe and well-informed and to evaluate their overall interaction
303 as affectively positive:

304 **Hypothesis 2.1 (H2.1).** For a smaller vehicle, the effect of the information richness of
305 eHMI communication (V2) on the perceived safety, the affective evaluation, i.e., affective
306 valence, arousal and dominance, and the perceived information quality is different compared to
307 a larger vehicle.

308 Dynamic eHMIs present overall a high information richness and can have a positive
309 effect on pedestrians' crossing behavior and perceived safety (Schieben et al., 2019; Wilbrink
310 et al., 2021). They can present information, e.g., only about the vehicle's intention, only about
311 the vehicle's perception or both information combined. The presentation of additional explicit
312 communication signals is generally perceived as beneficial and helped to resolve ambiguities
313 particularly in low-speed areas (Dey et al., 2020a; Faas et al., 2020; Lee et al., 2020; Schieben
314 et al., 2019b). Hence, it is assumed that a dynamic eHMI that combined information about the
315 VAS, the vehicle's intention and the vehicle's perception has a more positive effect on
316 pedestrians' perceived safety and subjective evaluation of the AV as a dynamic eHMI that
317 presents only the vehicle's intention or only the vehicle's perception.

318 **Hypothesis 3 (H3).** The dynamic eHMI that presents information about the VAS, the
319 vehicle's intention and the vehicle's perception leads to a higher perceived safety, a more
320 positive affective evaluation, i.e., affective valence, arousal and dominance, a higher perceived

321 information quality compared to a dynamic eHMI that only presents the vehicle's intention or
322 a dynamic eHMI that only presents the vehicle's perception (dynamic eHMI; V3).

323 **2 Method**

324 This study was aimed at further exploring the interaction between differently sized AVs
325 and pedestrians. This study focused on pedestrians' interaction with two differently sized AVs
326 (car, bus) which were equipped with a LED light-band eHMI on a shared space.

327 **2.1 Study design**

328 This study followed a 3x3x2 mixed design. The variable vehicle size (V1)
329 consisted of a smaller vehicle (car) and a larger vehicle (bus) and was manipulated within
330 participants. The variable information richness of eHMI communication (V2) had three levels
331 (no eHMI, static eHMI, dynamic eHMI) and was manipulated within participants. For the
332 variable dynamic eHMI (V3), three different dynamic eHMIs were presented (Vehicle
333 automation status (VAS) + intention; VAS + perception; VAS + intention + perception). This
334 variable was manipulated between participants.

335 **2.2 Independent variables**

336 **2.2.1 Vehicle size (V1)**

337 Two differently sized AVs (car vs. bus) were presented. The smaller vehicle corre-
338 sponded to a car, i.e., a BMW model i3, and the larger vehicle to a Mercedes Benz future bus.
339 Both AVs were equipped with the same eHMI communication strategies (see Table 1).

340 **2.2.2 Information richness of eHMI communication (V2)**

341 The information richness of eHMI communication included three gradings. For "no
342 eHMI", the vehicle did not display any explicit information to the pedestrian. This level served
343 as baseline. For the static and dynamic eHMI, a 360° LED light-band eHMI based on Wilbrink
344 (2018) was presented and located on the outer vehicle's body. The eHMI showed light signals

345 in the colour cyan. For the static eHMI, the eHMI was continuously lightened up to indicate the
346 VAS (see Table 1). For the dynamic eHMI, three different dynamic eHMI communication
347 strategies were presented (see Sec. 4.2.2.). In conclusion, the information richness was
348 considered for an AV with no eHMI, with static eHMI and with dynamic eHMI (“VAS +
349 intention”, “VAS + perception”, “VAS + intention + perception”).







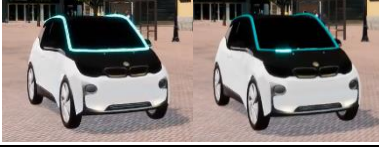



350 2.2.3 Dynamic eHMI (V3)

351 Three different dynamic eHMI communication strategies were presented as dynamic
352 eHMI (see Table 1) which displayed different information via the eHMI:

- 353 • **VAS + intention:** The eHMI showed the VAS. When the vehicle drove towards the
354 pedestrian, the eHMI light-band began to pulsate slowly (0.5 Hz) to indicate the
355 vehicle’s braking behavior. The light intensity diminished, then disappeared
356 completely and then established again. This cycle took place repeatedly until the
357 vehicle came to a full stop. The vehicle indicated its acceleration following the same
358 cycle but this time with a faster pulsation of the eHMI (1.0 Hz);
- 359 • **VAS + perception:** The eHMI showed the VAS. Additionally, as soon as the vehicle
360 perceived the pedestrian, a light segment on the LED light band was activated that
361 moved with the pedestrian as he/she crossed the shared space. It gave further explicit
362 communication information about the detection of the TPs;
- 363 • **VAS + intention + perception:** The eHMI showed the VAS. The two previous
364 described conditions were combined. The eHMI indicated the vehicle’s braking by
365 a slow pulsation. After the vehicle came to a complete stop, the light segment on the
366 eHMI switched on. Afterwards, the eHMI started to pulsate fast indicating the
367 vehicle’s acceleration.

368

369

Information richness	Vehicle size	
	Car	Bus
No eHMI		
Static eHMI (VAS)		
Dynamic eHMI		
VAS + intention		
VAS + perception		
VAS + intention + perception		

370 **Table 1.** Overview and illustration of the experimental conditions regarding “vehicle size” (V1), “information
371 richness of eHMI communication” (V2) and “dynamic eHMI” (V3) in this study.

372 2.3 Experimental setting

373 This study was conducted as an experimental online study using the SoSci ques-
374 tionnaire software (Leiner, 2019). The stimulus material was short video sequences shown from
375 an egocentric perspective in which the pedestrian interacted with the car and the public bus (see
376 Figure 1). The use case was a shared space, which was a traffic-calmed area in which minimum
377 traffic regulations existed, i.e., mutual understanding for each other, right-before-left rule and
378 a maximum velocity of 20 km/h (12.43 mph) (Clarke, 2006). The virtual urban traffic
379 environment was designed in virtual reality (VR) using the 3D creation software “Unreal
380 Engine” (Version 4.24.2). The vehicle’s deceleration process and speed were standardized for
381 all experimental conditions. Both vehicles drove with an initial speed of 20 km/h (12.43 mph).
382 In all conditions, the vehicle decelerated from 20 km/h (12.43 mph) to 5 km/h (3.12 mph) in
383 12.08m distance, from 5 km/h (3.12 mph) to 0 km/h in 9.29m distance, and stopped in 7.38m

384 distance. For conditions with dynamic eHMI (“VAS + intention”; “VAS + perception”; “VAS
 385 + intention + perception”), the eHMI started in 15.99m distance. All distances were measured
 386 from the vehicle’s front. In total, each participant saw six experimental video sequences (car
 387 without eHMI, bus without eHMI, car with static eHMI, bus with static eHMI, car with dynamic
 388 eHMI, bus with dynamic eHMI). Each video sequence was 50 seconds long. Regarding the
 389 dynamic eHMI, the participants experienced one of the three dynamic eHMI communication
 390 strategies (between-participants design). For all video sequences, the car was presented first
 391 and the bus second to ensure a consistent interaction pattern for the participants.



392

393 *Figure 1.* Illustration for the interaction between bus and pedestrian from two different angles: (left) approaching
 394 bus from the pedestrian’s left hand-side; (right) interaction between bus and pedestrian.

395 2.4 Sample

396 In total, $N = 155$ participants (55 female) with ages between 16 and 77 years ($M = 35.21$
 397 years; $SD = 15.29$ years) took part in the study. Overall, $n = 52$ participants interacted with the
 398 dynamic eHMI “VAS + intention”, $n = 50$ participants with the dynamic eHMI “VAS +
 399 perception”, and $n = 53$ participants with the dynamic eHMI “VAS + intention + perception”.
 400 The participants’ affinity for technology interaction (ATI) was measured with the standardized
 401 ATI questionnaire by Franke et al. (2018). The standardized ATI questionnaire is a tool to
 402 measure the user’s personality in the use of technology and consists of nine items (6-point
 403 Likert scale from 1 = “completely disagree” to 6 = “completely agree”) (Franke et al., 2018).
 404 In this study, the participants showed a rather high ATI ($M = 4.29$; $SD = 0.98$). Moreover, 80.60

405 % of the participants possessed a driving license. Mean driven km per year were 14,541.09 km
406 ($SD = 17,487.00$) / 9,035.41 mi ($SD = 10,865.92$ mi)). More than half of the participants (52.30
407 %) stated to carry out errands often on foot. Moreover, 84.50 % of the participants stated that
408 they carry errands rather in urban areas and only 15.50 % in rural areas. Regarding the
409 participants' prior experiences with AVs, $n = 152$ participants stated that they have heard of
410 AVs before. The participants rated a mid-ranged interest in AVs on a 5-point Likert scale from
411 (1 = "not at all" to 5 = "strong interest") with $M = 3.72$ ($SD = 1.11$). Furthermore, the
412 participants' prior experience with VR was rated with $M = 2.70$ ($SD = 1.16$) on a 5-point Likert
413 scale from (1 = "very little" to 5 = "very much").

414 The study was conceptualized and realized in accordance with the Declaration of
415 Helsinki. Informed consent was obtained from all participants before the experiment. The
416 participants were allowed to stop the study at any point without justification or consequence.
417 The participants volunteered, but received compensation for participation, four vouchers were
418 raffled under all participants. For the raffle, the participants could write down their mail address
419 which was stored separately from the experimental data to secure privacy. The participants were
420 recruited from an internal test driver database and from social networks. Three participants were
421 excluded from data analyses due to missing data. Furthermore, the diligence of the participants
422 was measured with a single item at the end of the questionnaire ("How careful did you conduct
423 the questionnaire?", 4-point Likert scale from 1 = "very careless" to 4 = "very careful"). Two
424 participants stated that they conducted the questionnaire very carelessly or carelessly and,
425 therefore, were excluded from further data analyses.

426 **2.5 Dependent variables**

427 Pedestrians' perceived safety ("For my personal safety, I found the behavior of the
428 vehicle to be safety enhancing.", scale from 1 = "totally disagree" to 7 = "totally agree") was
429 assessed on a 7-point Likert scale. The affective valence, affective arousal, and affective

430 dominance were measured with the Self-Assessment Manikin (SAM) questionnaire (Bradley
431 & Lang, 1994). The SAM questionnaire is a non-verbal method to assess an individuals'
432 subjective evaluation of the affective valence, arousal and dominance. For each dimension, five
433 graphic depictions were shown which were evaluated on 9-point Likert scales ranging for
434 affective valence from 1 = "unpleasant" to 9 = "pleasant", for affective arousal from 1 =
435 "aroused" to 9 = "calm" and for affective dominance from 1 = "no subjectively perceived
436 control over the situation" to 9 = "full control" (Bradley & Lang, 1994). Moreover, the
437 perceived information quality ("How well did you feel informed by the vehicle?", scale from 1
438 = "very bad" to 7 = "very good") was assessed on a 7-point Likert scale.

439 The usability of all eHMI communication strategies (static eHMI, dynamic eHMIs) was
440 investigated with a focus on the comprehension of the eHMI. Usability was defined as "the
441 extent to which a system, product or service can be used by specified users to achieve specified
442 goals with effectiveness, efficiency and satisfaction in a specified context of use" (p. 3) (DIN,
443 2018). In this study, it was investigated if the presented eHMI communication strategies were
444 clear and, thus, usable by specified users. Therefore, usability was measured with the semantic
445 differential "confusing-clear" (5-point Likert scale from 1 = "confusing" to 5 = "clear") of the
446 pragmatic quality scale of the User Experience Questionnaire Short Version (UEQ-S; (Schrepp,
447 Hinderks, & Thomaschewski, 2017)). The pragmatic quality of a system consists of all aspects
448 to what extent the product fulfils a user's individually set goals and can be understood as related
449 to usability (Hassenzahl, 2005; Hassenzahl & Roto, 2007). The usability was evaluated only
450 for the static and dynamic eHMI communication strategies and not for the baseline condition
451 (no eHMI). The reason was that in the baseline condition (no eHMI), no explicit information
452 were transmitted, i.e., the light-band eHMI was off.

453 **2.6 Procedure**

454 The online experiment started with clicking on a provided link. In the beginning,
455 information about the study's purpose, the processing of the data, and the privacy policy was
456 given. Informed consent was obtained. Additionally, participants were instructed that the
457 questionnaire should not be conducted with a smart phone as display problems could occur. In
458 a next step, the participants were randomly assigned to one of three questionnaires depending
459 on the dynamic eHMI (between-participants design). Demographical questions were asked
460 regarding age, sex, driver's license, driven kilometers per year as well as frequency and location
461 (urban vs. rural) of errands on foot. After this, the participants were asked to darken the current
462 environment to have good light conditions for the conduction of the experiment. This was
463 followed by a video check including a test video and the query if the video had worked.
464 Moreover, the participants were instructed to play the videos in full screen mode and guided
465 how to view the full screen mode to increase the immersion. The study could be further
466 processed only if the question was answered in the affirmative. The participants were not naïve
467 throughout the experiment as they received information about the shared space, the two AVs
468 and the LED light-band eHMI in a training phase before the experimental conditions. Moreover,
469 the eHMI communication strategies were explained. After this, the participants were instructed
470 that the egocentric video perspective represented their field of view and that they were
471 pedestrians who wanted to cross the shared space.

472 In the experimental phase, six video sequences were presented in which both AVs
473 approached the pedestrian from the left hand-side. The video perspective, i.e., pedestrian's point
474 of view, was towards the vehicle. Moreover, the traffic scenario was the same for all
475 experimental conditions. For all six video sequences, the no eHMI condition was presented first
476 as a baseline. The static and dynamic eHMI conditions were presented randomized. All
477 conditions were presented blockwise, i.e., the car first and the bus second to ensure a consistent
478 interaction pattern for the participants. In all videos, the participants stood on the same position

479 and looked to the left from where the vehicle (car vs. bus) drove towards them. After the vehicle
480 stopped, the pedestrian crossed the shared space and turned around to see the vehicle driving
481 away. After each video presentation, the participants were asked to rate their perceived safety,
482 their affective evaluation (SAM), and perceived information quality. Furthermore, the usability
483 was measured after each interaction with the static and the three dynamic eHMIs (“VAS +
484 intention”, “VAS + perception”, “VAS + intention + perception”). At the end of the experiment,
485 the participants indicated how carefully they had completed the questionnaire. Furthermore,
486 they could leave their e-mail address if they wanted to participate in the raffle of vouchers as
487 compensation. Overall, the total duration time of the experiment was approximately twenty
488 minutes.

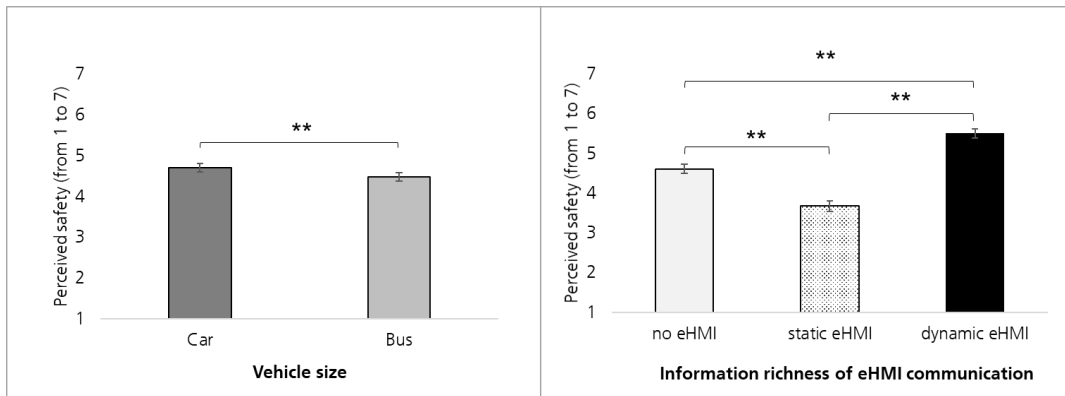
489 **3 Results**

490 Mixed ANOVAs were conducted with vehicle size (V1), information richness of eHMI
491 communication (V2) and dynamic eHMI (V3) (between-participants) as independent variables.
492 The data were checked for the assumption of a normal distribution which can be assumed due
493 to the sample sizes of each experimental group (Field, 2009). Furthermore, data were checked
494 for sphericity which were either given or adjusted with Huynh-Feldt correction (Field, 2009).
495 For significant main effects and interactions, pairwise comparisons with Bonferroni correction
496 were calculated and reported. For the mixed ANOVAs, the effect size was reported with partial
497 eta quadrat (η_p^2). According to (Cohen, 1988), the limits for the effect size were .01 (small
498 effect), .06 (medium effect), and .14 (large effect).

499 **3.1 Perceived safety**

500 A significant main effect for vehicle size (V1) [$F(1, 153) = 19.96, p < .001, \eta_p^2 = .115$]
501 showed that the participants' perceived safety was significantly higher for the car ($M = 4.71,$
502 $SD = 1.22$) compared to the bus ($M = 4.48, SD = 1.27$; Figure 2). Furthermore, a significant
503 main effect was found for information richness of eHMI communication (V2) [$F(2, 304) =$

504 98.74, $p < .001$, $\eta_p^2 = .394$]. Pairwise comparisons with Bonferroni correction showed that the
 505 perceived safety was significantly higher for an AV with dynamic eHMI ($M = 5.52$, $SD = 1.42$)
 506 compared to the static eHMI ($M = 3.68$, $SD = 1.64$) or no eHMI ($M = 4.62$, $SD = 1.49$; $p < .001$;
 507 Figure 2). Moreover, no eHMI lead to a significantly higher perceived safety compared to the
 508 static eHMI ($p < .001$).



509
 510 **Figure 2.** Pairwise comparisons with Bonferroni-correction for vehicle size (left) and for information richness of
 511 eHMI communication (right) for perceived safety. Error bars: ± 1 SE. ** $p < .01$ * $p < .05$

512 No significant differences were found regarding the dynamic eHMI (V3) ($p > .05$). The
 513 interaction between information richness of eHMI communication (V2) and vehicle size (V1)
 514 was also significant [$F(1.85, 281.05) = 6.43$, $p < .05$, $\eta_p^2 = .041$] with a rather small effect size.
 515 The interaction underlined the interpretability of the two main effects of information richness
 516 and vehicle size. Overall, H1 and H2 were confirmed in terms of the participants' perceived
 517 safety. Moreover, H2.1 was declined. Although the results indicated a significant interaction
 518 between vehicle size and information richness of eHMI communication, the effect size was
 519 rather small. H3 was declined as no significant differences between the dynamic eHMI
 520 communication strategies were found.

521 3.2 Affective Evaluation

522 Mean scores of each of the three SAM dimensions (affective valence, arousal,
 523 dominance) were calculated to assess the participants' affective evaluation and to look at
 524 differences in relation to the vehicle size, the information richness of eHMI communication and

525 the dynamic eHMI and the vehicle size. For vehicle size (V1), a significant main effect was
 526 found for all three SAM dimensions (Table 2). Pairwise comparisons with Bonferroni
 527 correction revealed that the participants reported a more positive affective valence, a lower
 528 affective arousal and a higher affective dominance for the car compared to the bus ($p < .05$;
 529 Figure 3).

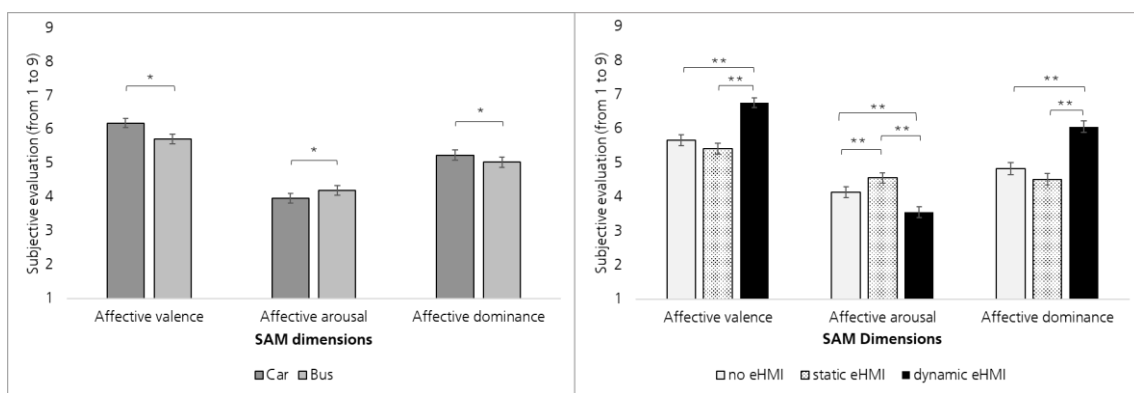
Measure	Variables	df^1, df^2	F	p	η_p^2
Affective valence (SAM)	Vehicle size	1, 152	40.37	.001 **	.210
	Information richness	2, 304	46.69	.001 **	.235
	Dynamic eHMI	2, 152	0.39	.680	.005
	Dynamic eHMI x information richness	4, 304	1.78	.134	.023
	Dynamic eHMI x vehicle size	2, 152	3.61	.029 *	.045
	Vehicle size x information richness	1.98, 301.55	2.65	.073	.017
	Dynamic eHMI x vehicle size x information richness	3.97, 301.55	1.65	.161	.021
Affective arousal (SAM)	Vehicle size	1, 152	11.22	.001 **	.069
	Information richness	1.97, 300.03	28.29	.001 **	.157
	Dynamic eHMI	2, 152	0.08	.925	.001
	Dynamic eHMI x information richness	3.95, 304	2.66	.034	.034
	Dynamic eHMI x vehicle size	2, 153	0.01	.992	.000
	Vehicle size x information richness	2, 304	4.71	.010 *	.030
	Dynamic eHMI x vehicle size x information richness	4, 304	1.20	.311	.016
Affective dominance (SAM)	Vehicle size	1, 152	11.95	.001 **	.073
	Information richness	1.95, 296.94	62.63	.001 **	.292
	Dynamic eHMI	2, 152	3.62	.029 *	.045
	Dynamic eHMI x information richness	3.91, 291.86	2.18	.073	.028
	Dynamic eHMI x vehicle size	2, 152	1.96	.145	.025
	Vehicle size x information richness	1.92, 291.15	1.03	.356	.007
	Dynamic eHMI x vehicle size x information richness	3.83, 291.15	0.15	.961	.002

530 **Table 2.** Inferential statistics for vehicle size (V1), information richness of eHMI communication (V2) and
 531 dynamic eHMI (V3) regarding the affective dimensions affective valence, affective arousal and affective
 532 dominance (SAM). * $p < .05$, ** $p < .001$.

533 For information richness of eHMI communication, a significant main effect was found
 534 for all three SAM dimensions (Table 2). Pairwise comparisons with Bonferroni correction
 535 revealed that the participants perceived a more positive affective valence when interacting with
 536 an AV with dynamic eHMI ($M = 6.77$, $SD = 1.81$) compared to static eHMI ($M = 5.42$, $SD =$
 537 2.07) or no eHMI ($M = 5.67$, $SD = 2.04$; $p < .001$; Figure 3). Furthermore, the participants felt
 538 more aroused with an AV with static eHMI ($M = 3.49$, $SD = 1.67$) compared to an AV with

539 dynamic eHMI ($M = 5.63$, $SD = 1.30$), static eHMI compared no eHMI ($M = 3.90$, $SD = 1.76$)
 540 and no eHMI compared to dynamic eHMI ($p < .001$). No significant difference was found
 541 between AV with static eHMI and dynamic eHMI ($p > .05$). Moreover, they reported a higher
 542 perceived dominance for an AV with dynamic eHMI ($M = 6.06$, $SD = 2.14$) compared to no
 543 eHMI ($M = 4.82$, $SD = 2.24$), for dynamic eHMI compared to static eHMI ($M = 4.51$, $SD =$
 544 2.14 ; $p < .001$; Figure 3).

545



546

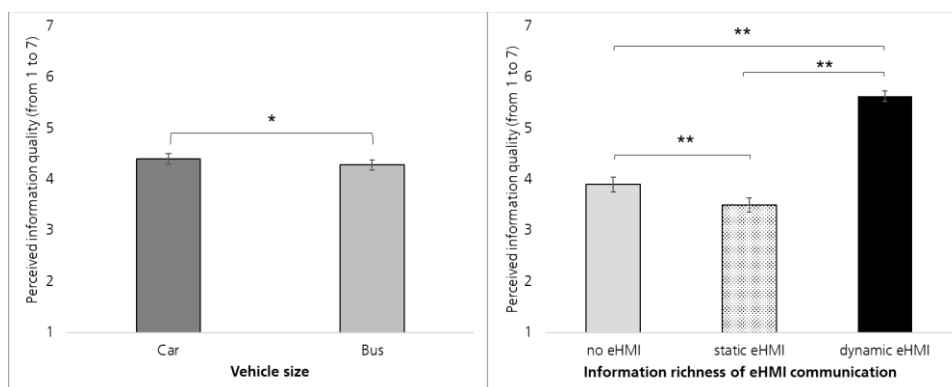
547 **Figure 3.** Pairwise comparisons with Bonferroni correction for vehicle size (left) and information richness of
 548 eHMI communication (right) for the SAM dimensions. Error bars: ± 1 SE. ** $p < .01$ * $p < .05$

549 A significant main effect of dynamic eHMI (V3) on the participants' affective
 550 dominance was found. Pairwise comparisons with Bonferroni correction showed that the
 551 participants perceived a higher dominance when they interacted with the "VAS + perception"
 552 dynamic eHMI ($M = 6.20$, $SD = 2.21$) compared to the "VAS + intention" dynamic eHMI (M
 553 $= 5.42$, $SD = 2.11$; $p < .05$).

554 Furthermore, significant interactions were found between vehicle size (V1) and dynamic
 555 eHMI (V3) on affective valence and between vehicle size (V1) and information richness of
 556 eHMI communication (V2) for affective arousal ($p < .01$; Table 2), but with small effect sizes.
 557 In conclusion, H1 and H2 were confirmed in terms of the affective dimensions. H3 was only
 558 confirmed for the affective dominance. Moreover, H2.1 was declined due to small effect sizes
 559 for the interaction between information richness and vehicle size.

560 3.3 Perceived information quality

561 A significant effect was found for vehicle size (V1) [$F(1, 152) = 8.51, p < .05, \eta_p^2 = .053$]
 562 indicating that the participants felt better informed by the car ($M = 4.40, SD = 1.29$) compared
 563 to the bus ($M = 4.28, SD = 1.25$; Figure 4). For the information richness of eHMI
 564 communication (V2), there was a significant main effect on the participants' perceived
 565 information quality [$F(2, 304) = 132.20, p < .001, \eta_p^2 = .465$]. Pairwise comparisons with
 566 Bonferroni correction revealed that, overall, the participants felt significantly better informed
 567 by an AV with dynamic eHMI ($M = 5.63, SD = 1.30$) compared to the static eHMI ($M = 3.49,$
 568 $SD = 1.67$), and no eHMI ($M = 3.90, SD = 1.78$; Figure 4). Moreover, they felt better informed
 569 by no eHMI compared to the static eHMI ($p < .05$). Overall, H1 and H2 were confirmed for the
 570 perceived information quality. All other hypotheses were declined.



571
 572 **Figure 4.** Pairwise comparisons with Bonferroni correction for vehicle size (left) and for information richness of
 573 eHMI communication (right) for perceived information quality. Error bars: ± 1 SE. ** $p < .01$ * $p < .05$

574 3.4 Usability of the eHMI communication strategies

575 The usability of the static eHMI and the three dynamic eHMI (“VAS + intention”, “VAS
 576 + perception”, “VAS + intention + perception”) was analysed. Multiple paired t -tests were
 577 calculated with a Bonferroni-corrected significance value of $p < .002$ investigating the
 578 difference between static and dynamic eHMI for each group (between-participants design). The
 579 participants that interacted with the “VAS + intention eHMI” rated it ($M = 3.51, SD = 1.20$) as
 580 more comprehensible compared to the static eHMI ($M = 2.77, SD = 1.29; t = -3.27, p < .05, n$
 581 $= 51$). The same result was found for the “VAS + perception” eHMI ($M = 3.78, SD = 1.13$)

582 compared with the static eHMI ($M = 2.84$, $SD = 1.11$; $t = -4.42$, $p < .001$, $n = 49$) and for the
583 “VAS + intention + perception” eHMI ($M = 3.74$, $SD = 1.11$) compared to the static eHMI (M
584 $= 2.98$, $SD = 1.18$; $t = -3.89$, $p < .001$, $n = 52$). Overall, the mean scores for all eHMI
585 communication strategies (including the static eHMI) indicated that the eHMIs were perceived
586 as clear. No significant differences were found between the three dynamic eHMIs ($p > .05$).

587 To sum up, all three dynamic eHMIs (“VAS + intention”, “VAS + perception”, “VAS
588 + intention + perception”) were perceived as more comprehensible compared to the static
589 eHMI. Moreover, the results indicated that all three dynamic eHMIs were rated equivalently
590 comprehensible. Therefore, H2 was confirmed in terms of the usability when comparing the
591 static eHMI with the dynamic eHMI in this study. There has been no comparison with the
592 condition no eHMI (baseline) as usability was not queried in this condition, because the eHMI
593 presented no explicit communication signals.

594 **4 Discussion**

595 In this study, one static and three dynamic eHMI communication strategies based on a
596 LED light-band were investigated for pedestrians’ interaction with a small and a large AV, i.e.,
597 a car and a bus. The presented eHMI communication strategies differed in their information
598 richness (no eHMI vs. static eHMI vs. dynamic eHMI). Furthermore, three dynamic eHMI
599 communication strategies were presented which displayed further information about the
600 vehicle’ intention and perception, in addition to the VAS. Results and implications for future
601 research are discussed in the following.

602 **4.1 Effect of vehicle size**

603 Previous research on the effects of eHMIs mostly focused on the applicability of eHMIs
604 on smaller vehicles (Dey et al., 2020a; Faas et al., 2020; Habibovic et al., 2018; Kaleefathullah
605 et al., 2020; Schieben et al., 2019b; Wilbrink et al., 2021). This study showed that eHMI

606 communication strategies can also be transferable to a larger sized AV, i.e., an automated bus.
607 Additionally, the vehicle size did not seem to influence the participants' information needs as
608 for both AVs they felt safer with a dynamic eHMI compared to a static eHMI (only presenting
609 the VAS) and no eHMI.

610 Pedestrians perceived and behaved differently when interacting with differently sized
611 vehicles which was investigated primarily with objective measurements (Beggiato et al., 2017;
612 DeLucia, 2013; Petzoldt, 2016). This study also demonstrated an effect of vehicle size by
613 focusing on subjective measurements, e.g., perceived safety, affective evaluation and perceived
614 information quality. The results revealed an effect of vehicle size for the interaction between
615 pedestrians and two differently sized AVs on a shared space, i.e., an automated car was
616 perceived as safer, evaluated with a more positive affective evaluation and a higher perceived
617 information quality compared to an automated bus. A possible explanation could be that even
618 though the participants interacted in pre-recorded video sequences, the larger AV was indeed
619 perceived as a bigger risk. This was also found by Dey et al. (2017) who compared a smaller
620 and a larger AV representing one of the few studies on the impact of vehicle size for AVs.
621 However, it needs to be addressed that the found differences for the car vs. the bus in terms of
622 pedestrians' perceived safety were rather small. The interaction with the two differently sized
623 AVs was only limited to pre-recorded videos and, therefore, pedestrians' evaluation might have
624 been influenced by the online presentation of the vehicles. Moreover, the participants felt
625 significantly better informed by an automated car compared to the automated bus although the
626 differences were only little. On the one hand, a possible explanation could be that the
627 participants felt more familiar with an automated car. On the other hand, it may also have
628 influenced that the participants expected more information by the bus as they usually display
629 further information, e.g., about the destination or the bus number. However, in this study,
630 additional information on the bus were excluded to avoid any additional visual stimuli on the
631 busses' front that might have attracted participants' attention. As the found differences between

632 car and bus were rather small, it needs further investigation in an experimental setting of higher
633 ecological validity to let the participants immerse into the interaction with an automated car and
634 an automated bus.

635 Additionally, it was investigated if the information richness of eHMI communication
636 might differ for differently sized AVs. This was not the case in this study as the results showed
637 similar findings, i.e., a higher perceived safety and a more positive effective evaluation for the
638 dynamic eHMI vs. static eHMI vs. no eHMI for both AVs. This gives a first evidence that
639 dynamic eHMI communication strategies are also applicable on a larger sized AV, an
640 automated bus. However, this study was conducted as an experimental online study and it needs
641 further investigation in more immersive experimental settings and a more realistic environment.
642 Additionally, differently sized AVs, e.g., automated shuttles, should be considered to further
643 investigate the effect of vehicle size in smaller increments. In conclusion, the results showed
644 that pedestrians' subjective evaluation in terms of perceived safety, affective evaluation as well
645 as the perceived information quality differed for the two differently sized AVs. In future studies,
646 the interplay between eHMI and the vehicle's driving behavior should be investigated to point
647 out if the effect of vehicle size was based on the eHMI communication or the vehicle's driving
648 behavior. Dey et al. (2017) pointed out that pedestrians' primary indicator for the crossing-
649 decision was the implicit communication presented by the vehicle. In this study, the vehicle's
650 driving behavior was controlled and held constant. The interplay of implicit and explicit
651 communication for differently sized AVs should be further evaluated in next studies.

652 All in all, the results pointed out that the pedestrians' subjective evaluation differed for
653 an automated car compared to an automated bus and supported previous research indicating
654 that larger vehicles are perceived as less safe compared to smaller ones. To this point, no clear
655 statement can be made on whether the effect of vehicle size is based on the vehicle's explicit
656 communication, i.e., eHMI, or the vehicle's implicit communication, i.e., driving behavior.

657 However, this study underlined that the dynamic eHMI impacted the pedestrians' perceived
658 safety and affective evaluation for both vehicles in a positive way.

659 **4.2 Pedestrians' information needs for the communication with AVs**

660 External human-machine interfaces need to match pedestrians' information needs to
661 enable a safe and well-working interaction with AVs in future mixed traffic (Ackermann et al.,
662 2019; Habibovic et al., 2018; Schneemann & Gohl, 2016). Previous research showed that the
663 use of eHMIs was especially relevant for low-speed and low-distance traffic scenarios in future
664 mixed traffic focusing on, e.g., parking scenarios and non-signalized street crossings
665 (Habibovic et al., 2018; Lee et al., 2020; Schieben et al., 2019b). This study investigated
666 different communication strategies of eHMIs for pedestrians' interaction with two differently
667 sized AVs on a shared space.

668 According to the results of this study, eHMIs also contributed to a well-working
669 interaction with pedestrians on a shared space as one example of a low-speed (maximum speed
670 of 20 km/h) and low-distance traffic scenario. We found a positive effect of a dynamic eHMI
671 on pedestrians' perceived safety and affective evaluation focusing on a shared space scenario
672 and, from this derived, a high information richness level of eHMI communication contributed
673 to a well-working future interaction in this study. This stands in line with previous studies
674 focusing on low-speed and low-distance traffic scenarios (e.g., Dey et al., 2020a; Habibovic et
675 al., 2018; Lee et al., 2020; Merat et al., 2018; Schieben et al., 2019b). However, our study
676 addressed a shared space traffic scenario more generally and it needs further in-depth
677 investigation to manifest the effects of differently sized AVs on shared spaces and to make
678 assumptions about how eHMI communication could contribute to a well-working interaction
679 on shared spaces (Li et al., 2021). Moreover, in this study, both AVs yielded in every video for
680 the pedestrian and, thus, behaved according to the rule (right-before-left). As on shared spaces,
681 vehicles could approach from both sides, the direction from which the AVs approach (right vs.

682 left) should be varied in future research. This would further investigate if pedestrians' feeling
683 to have the right of way might have influenced their subjective evaluation of their interaction
684 on a shared space.

685 There has been contrasting results on what kind of information pedestrians required for
686 the interaction with AVs. On the one hand, pedestrians requested only additional information
687 by the AV when it did not behave as expected (Rothenbacher et al., 2015). On the other hand,
688 pedestrians requested a high information richness for the interaction with AVs, e.g., information
689 about the VAS and/or further information about the vehicle's intention and perception (Faas et
690 al., 2020; Habibovic et al., 2018; Lundgren et al., 2017; Schieben et al., 2019a). This study
691 showed a clear positive impact of dynamic eHMIs showing a high information richness on
692 pedestrians' perceived safety, affective evaluation, perceived information quality, and usability
693 for the interaction on a shared space. More precisely, the participants perceived the interaction
694 with a dynamic eHMI as safer, evaluated it with a more positive affective evaluation and a
695 higher information quality compared to the mere presentation of a static eHMI or no eHMI at
696 all. This stands in line with findings of Schieben et al. (2019b).

697 A comparison between different dynamic eHMIs (VAS + vehicle's intention, VAS +
698 vehicle's perception and VAS + intention + perception), which all had a high information
699 richness level, revealed no differences between three dynamic eHMIs. This leads to the
700 conclusion that all dynamic eHMIs seemed to allow appropriate interaction with the two AVs
701 and for the use case shared space as previously shown for other traffic scenarios (Schieben et
702 al., 2019a; Schieben et al., 2019b; Wilbrink et al., 2021). The authors approved the same LED
703 light-band eHMI concept for pedestrians' interaction with an automated car in the use cases of
704 a non-signalized intersection and a parking scenario (Kettwich et al., 2019; Schieben et al.,
705 2019b; Wilbrink et al., 2021). Only for the affective dominance, the results indicated that the
706 participants felt more dominant when the dynamic eHMI presented the vehicle's perception

707 compared to the vehicle's intention. This stands in clear contrast to findings of Faas et al. (2020)
708 that revealed no additional impact of an eHMI presenting the vehicle's perception. However, it
709 is not clear to which extent participants were able to experience dominance as the interaction
710 was based on pre-recorded interactions. Regarding the usability, all eHMIs (dynamic eHMI,
711 static eHMI) were perceived as clear. Further comparisons between the static and dynamic
712 eHMI revealed that the dynamic eHMI is perceived as statistically clearer. This demonstrated
713 that the participants preferred a high information richness over the mere presentation of the
714 VAS to understand the vehicle's behavior. Moreover, it showed that the participants perceived
715 all eHMI communication strategies as clear even the participants interacted with the presented
716 eHMI communication strategies for the first time. This supports findings reported by Avsar et
717 al. (2021) who showed that pedestrians understood these eHMI communication strategies after
718 only one interaction. However, this study focused on only one aspect of usability, i.e., the
719 comprehension of eHMI strategies. It requires further consideration of other relevant aspects
720 for a detailed assessment of usability, e.g., the efficiency in future work.

721 Surprisingly, results suggested that the static eHMI which displayed the mere
722 presentation of the VAS was evaluated with a lower perceived safety, a more negative affective
723 evaluation and a lower information quality compared to no information at all. Nevertheless,
724 these findings contradicted previous studies showing that pedestrians requested information
725 about the VAS (Habibovic et al., 2018; Habibovic et al., 2019; Lundgren et al., 2017; Schieben
726 et al., 2019a). A possible explanation could be that when they interacted with an AV with static
727 eHMI, the participants became uncertain as they were not familiar with the interaction with an
728 AV and with an eHMI in general. Moreover, they might have expected that the vehicle would
729 give more information than just the mere automation status. However, the effect may also be
730 related to the conduction of the experiment. The participants received information about both,
731 the static and dynamic eHMI, in the instruction phase. In the experimental phase, the
732 participants interacted randomly with the static or dynamic eHMI. When the participants

733 experienced the static before the dynamic eHMI, they could have expected more than the mere
734 presentation of the VAS and were not satisfied with it. However, the VAS displayed important
735 information to distinguish a non-automated vehicle from an AV in mixed urban traffic
736 (Schieben et al., 2019a).

737 **4.3 Limitations and future work**

738 This study was an experimental online study in which the participants interacted in
739 standardized pre-recorded video sequences with both AVs and, therefore, their interaction with
740 the AVs was limited. Future studies should be conducted in a more immersive experimental
741 setting, e.g., in VR environment, where the participants were able to better experience the
742 different vehicle sizes. Moreover, as the participants experienced only short interactions in this
743 study, this study reflected only partially the interaction between pedestrians and differently
744 sized vehicles in urban traffic. Future studies need to enable a longer and more realistic
745 interaction and, additionally, with a higher complexity including multiple TPs interacting at the
746 same time. Furthermore, different age groups should be considered in future work, e.g., younger
747 participants (< 16 years) who have only little driving experience but will actively participate in
748 future urban traffic. Additionally, pedestrians' crossing behaviour for the interaction with
749 differently sized AVs should be investigated in terms of objective measures, e.g., crossing onset
750 and initiation time. Moreover, the interplay of implicit communication, i.e., vehicle's driving
751 behavior, and explicit communication, i.e., via eHMIs, should be further investigated towards
752 a holistic communication strategy.

753 **4.4 Conclusion**

754 This study was aimed at shedding light on the design of eHMIs for differently sized AVs
755 and their interactions with pedestrians on a shared space. The results underlined the
756 transferability of dynamic eHMI communication strategies to a larger sized AV and,
757 additionally, the applicability of those eHMIs for the interaction on a shared space. This work

758 clearly contributed to on-going eHMI research that focuses on the standardization and
759 reliability of eHMIs on a broader spectrum. The overall goal was to define a systematic
760 approach for the use of eHMI communication strategies that represented not only a compilation
761 of relevant influencing factors, but also the causal relationships. This would enable valid
762 statements on how to design and to implement safe and efficient eHMIs in future urban traffic,
763 e.g., vehicle-specific eHMIs. Coming back to the title question if one solution fits all – this
764 study showed that dynamic light-based eHMI communication strategies worked well for both
765 AVs and their interactions with pedestrians on a shared space. To sum up, the light-based eHMI
766 did not only have the potential to increase traffic safety for the interaction an automated car,
767 but also for the interaction with an automated bus in this study. For the evaluation of the full
768 potential of a light-band eHMI, research on other sized AVs and more complex traffic scenarios
769 will be conducted to answer the question in its entirety.

770 **Declarations of interest**

771 None.

772

773 **Ethics statement**

774 The study was conducted in accordance with the Declaration of Helsinki.

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778 **Author Contributions**

779 Merle Lau: Conceptualization, Methodology, Data curation, Writing- Original draft,
780 Visualization, Validation, Resources, Formal analysis, Investigation, Software, Writing-

781 Review and editing, Project administration; Meike Jipp: Writing – Review and editing;
782 Supervision; Michael Oehl: Conceptualization, Methodology, Visualization, Validation,
783 Writing- Review and editing, Resources, Supervision, Project administration, Funding
784 acquisition

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