

Investigating the Effects of External Communication and Platoon Behavior on Manual Drivers at Highway Access

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Automated vehicles are expected to improve traffic safety and efficiency. One approach to achieve this is via platooning, that is, (automated) vehicles can drive behind each other at very close proximity to reduce air resistance. However, this behavior could lead to difficulties in mixed traffic, for example, when manual drivers try to enter a highway. Therefore, we report the results of a within-subject Virtual Reality study (N=29) evaluating different platoon behaviors (single vs. multiple, i.e., four, gaps) and communication strategies (HUD, AR, attached displays). Results show that AR communication reduced mental workload, improved perceived safety, and a single big gap led to the safest merging behavior. Our work helps to incorporate novel behavior enabled by automation into general traffic better.

CCS Concepts: • **Human-centered computing** → **Empirical studies in HCI**.

Additional Key Words and Phrases: Automated vehicles; self-driving vehicles; external communication; Virtual Reality.

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1 INTRODUCTION

Automated vehicles (AVs) will change traffic both for vulnerable road users (VRUs) such as pedestrians [17, 30, 37] as well as for manual drivers [11, 57, 58]. Anticipated benefits such as reduced accidents [67] and improved fuel usage either by improved driving [1] or via novel behaviors such as platooning [1] drive the development of these systems. Especially platooning, that is, a system in which several (automated) vehicles can drive behind each other at a very close distance of 10m or less [1, 3, 38, 40] with the aid of a technical control system without compromising road safety, has been researched extensively [1] and is being evaluated with trucks on real streets since 2018¹.

While numerous works investigated the crossing process of VRUs (e.g., the impact of vehicle shape [25], modality [20], or scenario [16]), the potential encounters of AVs with manually driven vehicles (“manual drivers”) have been less investigated. In these encounters, there exists the possibility for uncertainty, for example, when the road is partially blocked [44, 57]. Another source of uncertainty to manual drivers is unknown driving behavior by AVs. One particularly well-evaluated approach for AVs to improve road efficiency is platooning. However, this introduces “a new cooperative driving paradigm for drivers”[1, p. 1]. In the very likely transitional phase during which AVs and manual drivers co-exist on the roads, AV approaches must account for human behavior and vice-versa. With platoons in mind, there could be

¹<https://www.truckinginfo.com/278839/real-world-truck-platooning-test-with-real-truck-drivers>; Accessed: 12.12.2022

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53 two difficulties: merging into a, potentially, long platoon on highway entries and traveling in a platoon as a manual
54 driver. In this work, we focus on the highway entry with an approaching platoon. Driving onto a highway today is
55 already a complex scenario [70]. With an approaching platoon, this could become unfeasible; therefore, the platoon's
56 behavior must be adapted. While the platoon could dissolve prior to every entry, this would make it very inefficient.
57 Therefore, different approaches are required. With real-world testing undergoing since 2018 and with legislature coming
58 up to date with AV technology (e.g., in Germany²), the emergence of this scenario becomes within reach in the next
59 decade and has to be designed in a safe way.
60

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62 Therefore, we investigated a highway merging scenario with an approaching car platoon in a within-subjects virtual
63 reality (VR) study with N=29 participants. To address the complexity of highway entry, there are two alterations possible:
64 altering the behavior and altering available information to the manual driver. Therefore, we altered the platoon behavior
65 by providing single gaps (35 or 70m long) or multiple gaps (30 or 45m long) and provided three communication designs:
66 Augmented Reality (AR)-based, using a Head-Up Display (HUD), or attached displays on the AVs alongside a baseline.
67 We found that the large single gap and the AR communication were clearly preferred. The AR concept also significantly
68 increased trust and predictability. The large single gap also led to significantly fewer crashes.
69

70 *Contribution Statement:* This work provides two platooning behaviors usable for the merging of manual drivers onto
71 automated highways. Three communication concepts (AR, attached displays, and a HUD) are also defined. Findings of a
72 VR study with N=29 participants show that the large single gap and the AR communication were clearly preferred and
73 led to higher trust and fewer crashes.
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76 2 RELATED WORK

77
78 This work is based on research in the field of external communication of AVs toward manual drivers. However, we also
79 provide general insights from studies on external communication of AVs towards pedestrians as these can also guide
80 the design for other road users.
81

82 2.1 External Communication Towards Vulnerable Road Users

83
84 Vulnerable road users such as pedestrians or bicyclists, that is, road users not protected by an outside shield [37],
85 communicate in traffic scenarios with ambiguous right of way via eye gaze or gestures. Recent research has looked into
86 how a missing human driver in a vehicle that is communicating with vulnerable road users (e.g., by waving or nodding)
87 could be substituted or whether this communication process could even be enhanced [20]. The design of these concepts
88 varies regarding modality, message type, and communication location [17]. Also, situation characteristics have to be
89 considered.
90

91
92 While several modalities have been evaluated, visual communication concepts were mostly used [21]. Current
93 research focuses on scalability [10, 22], accessibility [21], and social aspects [61]. Also, potential challenges regarding
94 passenger actions, such as pedestrian mode confusion, are evaluated [13, 23].
95

96 2.2 External Communication Towards Manual Drivers

97
98 While communication to VRUs has gained significant attraction in recent research, communication toward manual
99 drivers has been investigated less. Therefore, we recapitulate the findings of related work on any communication
100 towards manual drivers to derive our communication concepts.
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103 ²<https://www.bundesregierung.de/breg-en/news/faq-autonomous-driving-1916398>; Accessed: 12.12.2022

105 Rettenmaier et al. [57] investigated the communication between an AV and a manual driver in such a bottleneck
106 situation. In their task, two parked automobiles block the road, forcing both the MV and the AV to utilize the oncoming
107 traffic lane to pass the parked vehicle. As a result, both cars must cede the right-of-way to the oncoming vehicle in
108 an uncontrolled circumstance. As a result, communication is essential. The communication is accomplished using
109 displays on the AV's radiator grill or road projections. The screens depicted German road signs, which are commonly
110 used to control traffic during bottlenecks. The study found that displays outperformed projectors in terms of visibility,
111 especially at larger distances [57]. Because the driver's gaze is largely oriented upon the approaching AV, the display is
112 detected earlier. Furthermore, the projections are transparent and hence less apparent than the screens. Nonetheless,
113 Miller et al. [49] also found that perceivable implicit communication, that is, clearly visible movement, can suffice for
114 bottleneck scenarios.
115

116
117 Also, in a bottleneck scenario, Rettenmaier et al. [56] changed the visual signals to communicate the AV's purpose to
118 the manual driver. This study yielded the best design for communication visualization in the form of a red or green
119 colored arrow.
120

121 Klaus et al. [41] discussed various forms of communication. They differentiate between four external human-machine
122 interfaces (eHMIs): "marking a vehicle as an automated vehicle", "light strips", "display," which shows texts or symbols,
123 and "projection". They believe that the latter two eHMIs are more beneficial for communicating with other road users
124 since their displays and projections can present a huge quantity of information (textual or pictorial).
125

126 Avsar et al. [2] investigated an intersection (i.e., a T-junction) scenario. Here, an AV had the right of way but still
127 yielded to a manual driver, communicating this via a "360° LED light-band" [2]. They discovered that the eHMIs improved
128 perceived safety and trust in the AV and that handling was assessed as simpler. This reinforces the notion that eHMIs
129 improve traffic and communication with manual drivers.
130

131 Schlackl et al. [64] used the whole visible car body. They investigated the zipper procedure at a road extension (i.e., a
132 construction site). The zipper procedure is also performed when merging onto a highway, as is done in our experiment.
133 The eHMI had three parts: the hood, the rear, and the driver's side. In the shape of a dot, the side recorded the location
134 of the observed vehicle driving next to the AV. This was to compensate for the lack of eye contact. The traffic status
135 was depicted as a symbol on the vehicle's back. Triangles pointing and moving in the direction the participants were
136 intended to turn in were visible on the front of the AV. Pictograms and triangles were "much better than the ordinary
137 headlight flasher" [64, p. 82].
138

139
140 Colley et al. [11] investigated two scenarios. First, they evaluated a scenario with emergency vehicles where the AV
141 would communicate the situation or block the intersection for vehicles other than the emergency vehicle by driving
142 into it. While external communication aided in understanding the behavior, participants were still confused by this
143 novel behavior. In the second scenario, a four-way intersection was investigated. In this deadlock scenario, external
144 communication led to a lower mental workload and fewer accidents, showing the potential of this communication.
145

146 These works show that eHMIs have the potential to communicate with other manual drivers but that also implicit
147 communication can suffice. We draw from these previous works in designing our communication concepts and further
148 the understanding how such communication can affect drivers in a novel situation, i.e., the merging into a platoon.
149 While one zipper scenario was evaluated, there currently is a knowledge cap in understanding merging scenarios with
150 platoons.
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2.3 Platooning of Automated Vehicles

Due to different objectives and motivations, various approaches exist for platooning strategies. While some strategies seek to establish a commercial fleet or implement platooning as a service [47], others are interested in increasing safety, reducing congestion, or simply compensating for the lack of skilled drivers [5]. These strategies can be distinguished according to the following criteria:

- (1) what type of control is exercised (longitudinal such as keeping an adequate gap between vehicles and appropriate speed and/or lateral, such as steering);
- (2) what type of platoon structure is required (heterogeneous or homogeneous, i.e., are only vehicles of the same type, such as trucks of a specific brand allowed);
- (3) what type of technology is needed (is it necessary to adapt the infrastructure, for example, with additional sensors such as cameras, or is it possible without it)

In this study, we focused on a homogeneous platoon where longitudinal control is exercised, and no additional infrastructure is needed. We opted for a homogeneous platoon as this reduces unintended side effects such as having to merge in front of vehicles with variable sizes or different colors as this might influence attributions of speed [24]. Only longitudinal control was simulated, as swaying to different lanes is potentially dangerous if other vehicles are present. The *SARTRE* [5, 59, 62] strategy is an example of such a solution. The idea is to develop and implement traffic solutions so that it will be possible to do platooning without having to modify the infrastructure. It defines a platoon as a heterogeneous combination of vehicles led by a heavy manual vehicle. All following vehicles orientate themselves to the lead vehicle. Using V2V communication, the specified distances and paths are communicated to the following vehicles. Therefore, longitudinal and lateral control is needed in this strategy. Important to mention here is that in this strategy, platoons do not have a fixed size but behave dynamically. Vehicles can join or separate dynamically. Moreover, in an emergency or with loss of communication, the local system, i.e., the vehicle itself, will take over control again. Kühn et al. [43] have already investigated human reactions to potential AVs on highways in various scenarios. They conducted a simulation study to determine whether human drivers could, in general, detect an AV based on its driving behavior, finding that human drivers could recognize this quite well. They already had appropriate ideas about potential interaction scenarios and possibilities about AVs and the way they would behave. Various scenarios were investigated for this purpose, including one where the subject had to enter the highway and line up in front of an AV. It was found that it was more pleasant for the subject when the AV kept a relatively large safety distance after the vehicle had entered the lane [43]. However, Kühn et al. [43] only investigated single-vehicle scenarios.

van Loon and Martens [68] have collected different concepts that address the compatibility problems during this transition phase of mixed traffic. Optimal driving patterns are often assumed in theory. However, this cannot always be guaranteed, especially in mixed-traffic situations [68]. For instance, on the highway at an on-ramp, one cannot always switch to the left lane to ease merging for entering vehicles, as human drivers are also present and usually want to pass a slower vehicle.

Therefore, AVs in mixed traffic will need to be able to co-exist and cooperate with manually driven vehicles (i.e., achieve so-called “backward compatibility”). Thus, AVs require the ability to anticipate the behavior of vehicles unequipped with the latest technology based on measurable indicators such as their speed or acceleration and to react accordingly. Clearly, it would also be important to have forward compatibility, i.e., unequipped vehicles interacting with an AV and not noticing any difference from a human driver. However, this will be less apparent due to the nature of AVs, as they

will be designed to drive efficiently and safely, which may contrast with human driving behavior [68]. Woodman et al. [73] previously studied low-speed platoons of AVs in inner-city environments via focus groups. They used low-speed autonomous transport systems (L-SATS), which were equipped with eHMIs to communicate with pedestrians. They assumed a platoon that does *not* operate completely autonomously. At the start of the platoon, the AV is supervised by a human who can intervene in an emergency. Within this context, it was interesting that the participants had more confidence in the stopping capabilities of the AVs than in those of normal vehicles. One of the aspects the participants were concerned about was the spacing of the individual AVs. Thus, on the one hand, they were concerned about safety and whether the AVs would not crash into each other. On the other hand, they were concerned that people or animals could walk between them if the distance became too great.

Gilbert et al. [33] investigated the public perception of the number, affiliation, and purpose of AVs in shared lanes. In their survey, they found that fleets, and especially fleets associated with a private agency, were perceived as less positive compared to single or public agency-associated AV fleets. Therefore, we refrained from defining the association to a private or public agency.

Finally, Razmi Rad et al. [53] evaluated the impact of a platoon driving in a dedicated lane **next** to manual drivers. They found that manual drivers accepted shorter gaps when driving next to the dedicated lane.

This overview shows that the topic of platooning is challenging both from the technical as well as from the human factor perspective. While a lot of work has gone into improving the technical capabilities, only theoretical [68], survey [33], or focus groups [73], simple [43] or scenarios with dedicated lanes [53] were conducted to approach human factor challenges. Empirically evaluating drivers' behavior in more complex (i.e., multiple vehicles, multiple lanes) scenarios with different platoon behaviors and communication concepts to support the manual driver is currently missing.

3 EXPERIMENT

We designed and conducted a within-subject study to evaluate the effects of various platoon behaviors and communication concepts. This study was guided by the exploratory research question (RQ):

RQ1: What impact do the variable **platoon behavior** and **communication** have on manual drivers in terms of (1) driving behavior, (2) mental workload, (3) trust, (4) perceived safety, and (5) communication quality?

These measurements were used in previous literature to assess different behaviors and communication possibilities. We expect that lower mental workload and higher trust, perceived safety, and communication quality are desirable aspects of the merging process. Due to the exploratory nature of this study, we refrain from stating hypotheses. Behavior was measured by eye gaze and driving-related measures regarding the merging, such as distance and speed (see Section 3.2.1). The measured behavior was important to adequately assess objective metrics for the merging process.

Every participant experienced 17 conditions, resembling a 4×4 design plus a baseline (no communication and no gap adaption). The independent variables were platooning behavior (Single Small Gap, Single Large Gap, Multi Small Gaps, Multi Large Gaps) and communication concept (No Communication, AR, eHMI, HUD). In the baseline, the platoon would not alter a gap, so no gap other than the initial 5m between each vehicle was created.

3.1 Materials

3.1.1 *Virtual Reality Simulator.* We modeled the scenarios in Unity version 2021.3.10f1 [66]. We used a Thrustmaster T150 Pro steering wheel with pedals and an HTC VIVE Pro Eye. This allowed the participants to look over their shoulders and, for example, check the blind spot. We used the Simple Traffic System asset [65] with several modifications to generate traffic. Participants drove a vehicle with 5m length, 2.05m width, and a height of 1.7m. This approximately represents a Volkswagen Passat Limousine.

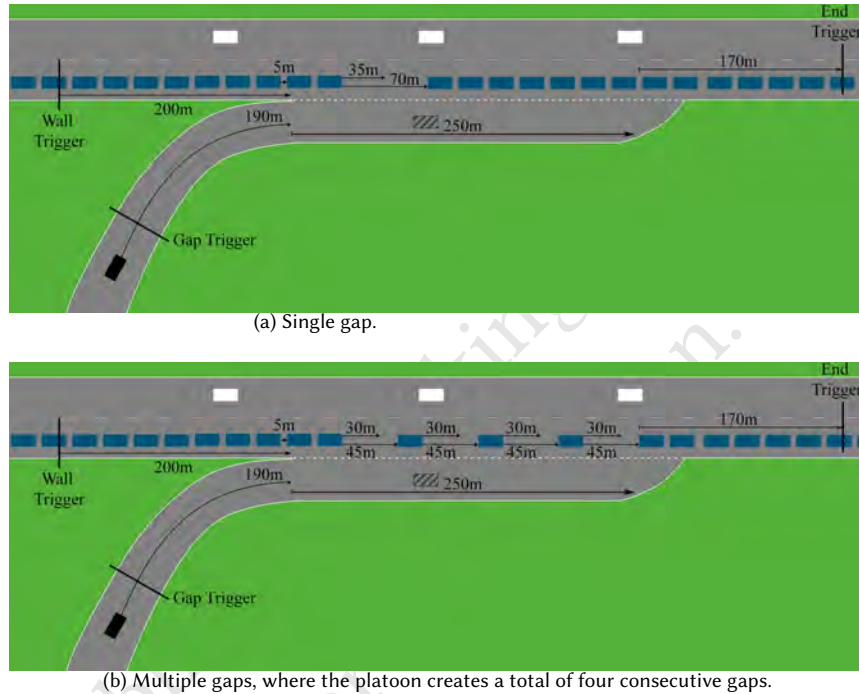


Fig. 1. Platooning behavior used for the VR study (vehicles not to scale). The solid black rectangle represents the starting position, the striped rectangle an arbitrary position on the acceleration lane. The start point is approximately 100m before the turn, visible on the lower left side.

3.1.2 *Platooning Behavior.* The platoon operated with a distance of 5m between AVs and consisted of 103 vehicles. This number was chosen to ensure that the participant will encounter the platoon when merging. While previous work often assumes a maximum platoon size of < 10 [48, 74] to achieve high traffic stability, Zhou and Zhu [74] showed that higher numbers increase capacity and are feasible without too high degradation in traffic stability. The platoon traveled at a speed of 130km/h, the typical velocity, for example, recommended on German highways.

We implemented two different types of platooning behavior in the case of merging: forming one gap (see Figure 1a) or multiple (i.e., four consecutive gaps in our study) smaller gaps (see Figure 1b). As we were interested in different required sizes for the gaps, after initial testing, we chose 35 and 70 m for the single gap and 30 and 45m for the multiple gaps. To determine the proper gap sizes, we followed the recommended safety distance on German highways. According to German law, the safety distance to the preceding vehicle has to be large enough to ensure that the driver can stop their car without any problems if the preceding vehicle brakes unexpectedly [54]. For this purpose, it is common to use

a rule of thumb that states that the distance to the preceding vehicle should be approximately the equivalent in meters of half the own current speed [54]. As all vehicles in our study were traveling at 130 km/h on the highway, the correct safety distance, therefore, would be 65m. We used this recommendation as a starting point for the gap sizes. Initially, we tested gap sizes of 15m (multiple small) and 30m (multiple big gaps). Based on this, we determined that the gap size should be at least 30m to keep the task from being too challenging and reduce potential crashes. This led to the condition of multiple small gaps with 30m distance. Following the recommended safety distance, we chose 70m as the maximum gap size, which is even slightly larger. We chose 35m for the single small gap size as it is half of the single big gap size and also still higher than the finable distance [54]. As we also wanted to consider efficiency, we could not make the gaps too big, as, for example, a gap size of 50m would result in a total size of 200m with multiple gaps. This would only leave a 50m buffer at the entrance to the highway, which we considered difficult for the driver. Therefore, we again oriented ourselves to the recommended minimum distance and used the gap size of the single big gap as an appropriate buffer. This resulted in a gap size of 45m ($250m - 70m = 180m$, divided by 4) for the multiple big gaps.

The gap(s) were formed as follows: when the participant drove past a trigger in the curve leading to the acceleration lane (see "gap trigger" in Figure 1), the gap was formed approximately 200m to the left of the start of the acceleration lane (see "wall trigger" in Figure 1). In internal tests, this distance was found to be appropriate to allow the gap to be at the end of the acceleration lane when the participant continued to drive regularly.



Fig. 2. Communication concepts used in the study.

3.1.3 Communication Concept. We implemented three communication concepts based on prior work along with having no communication as the fourth level of the factor *communication concept*.

365 **AR:** The AR visualization (see Figure 2a) employs a simulated AR windshield to directly (i.e., contact analog) display
366 gaps that were created for merging. This concept closely relates to the concept of Lorenz et al. [45] who found that
367 visualizing the permitted/suggested area (via AR in green) for driving after a takeover led to better reactions than
368 visualizing the prohibited/unfeasible area. The simulated AR windshield extends to the side windows as frequent
369 shoulder checking will be required for entering the highway.

371 **eHMI:** The attached display (called eHMI; see Figure 2b) refers to concepts currently evaluated in external communi-
372 cation of AVs with manual drivers such as Colley et al. [11] and Rettenmaier et al. [57]. The green arrow signals which
373 gap to join, while the red line indicates an unfeasible gap. The eHMI had high visibility from the driver's perspective.

375 **HUD:** The HUD (see Figure 2c) does not directly incorporate information on which gap can be joined but only
376 that there is a feasible gap by displaying the word "Free". This approach requires the least technical adaptation. In the
377 current version, the HUD only contains information about the gap. Therefore, cognitive overload is unlikely due to the
378 textual nature of the information. Additionally, the text is marked in green (see Figure 2c) to facilitate its recognition.
379 We were also inspired by the HMIs incorporating information for the takeover process, which often contained text
380 (e.g., see [12, 28, 69]). Nonetheless, Charissis and Papanastasiou [6] explain that "HUDs overloaded with information,
382 especially those using textual output, can create the effect known as cognitive capture [6, p. 43]. Therefore, future
383 interfaces should evaluate the use of pictorial visualization.
384

385 AR and eHMI represent **localized** information, that is, information regarding the merging process is located at the
386 relevant position. The HUD represents aggregated information. This enables us to study the effects of these different
387 kinds of information presentation.
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390 3.2 Measurements

391 3.2.1 *Objective measurements:* We measured position, speed, and eye-tracking data at 66 Hz. We logged several areas
392 of interest: every vehicle (defined by a unique id) and the different visualizations (AR, HUD, eHMIs). For the AR
393 visualization, only when the gaze was upon the green area was logged as a fixation (i.e., not the entire window that
394 was simulated as being an AR windshield), for the HUD, the area of the text was defined as gazable area, and for the
395 eHMI, the displays on the vehicles were the area of interest. Additionally, we logged the time needed overall, time to
396 arrival at the ramp, time on-ramp, the time needed to join, whether the participant joined the platoon in one of the
397 gaps (boolean), and whether the participant let the entire platoon pass (boolean), coordinate of the join (x,y,z), which
398 gap was used to join (int), distance to the front and back car at join (in m), the speed at join (in km/h), join attempts
399 (int), crashed with AVs (boolean), and the number of crashes (int). These measures enabled us to answer our RQ with
400 regard to driving behavior.
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403

404 3.2.2 *Subjective Measurements.* Participants rated their perceived safety using four 7-point semantic differentials from
405 -3 (anxious/agitated/unsafe/timid) to +3 (relaxed/calm/safe/confident) as used by Faas et al. [29]. We also employed the
406 mental workload subscale of the raw NASA-TLX [34] on a 20-point scale ("How much mental and perceptual activity
407 was required? Was the task easy or demanding, simple or complex?"; 1=Very Low to 20=Very High). Additionally, we
408 used the subscales *Predictability/Understandability* (*Understanding* from here) and *Trust of the Trust in Automation*
409 questionnaire by Körber [42]. Understanding is measured using agreement on four statements ("The system state was
410 always clear to me.", "I was able to understand why things happened."; two inverse: "The system reacts unpredictably.",
411 "It's difficult to identify what the system will do next.") using 5-point Likert scales (1=Strongly disagree to 5=Strongly
412 agree). Trust is measured via agreement on equal 5-point Likert scales on two statements ("I trust the system." and
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“I can rely on the system.”). The system was introduced as the whole platoon. In addition, situation awareness was assessed using a self-defined statement (“It was clear to me at all times what the other road users were doing.”). The behavior (“The behavior of the other vehicles was clear.”) and the communication quality (“The communication for filtering/merging into traffic was clear.”) were also assessed using agreement on a 7-point Likert scale (1=totally disagree to 7=totally agree). After all 17 conditions, participants could provide positive and negative open-ended feedback.

3.3 Procedure

Each participant began by signing a consent statement. Every participant had to have a valid driver's license. Following that, we gave each participant a brief overview of the study. Afterward, participants could familiarize themselves with the steering wheel and the VR environment by driving onto the highway at least three times. In these trial runs, there was reduced traffic and no platoon approaching. On average, participants tried the scenario five times. Participants were allowed to drive as long as they wanted. Following this, the participants encountered all seventeen conditions counterbalanced once (thus, constituting a within-subjects design). The introduction to the scenario was (Translated from German):

Introduction: You will drive onto a highway in a virtual reality (VR) environment in a self-driven vehicle. You will encounter automated and manually controlled vehicles. Automated driving vehicles can be recognized by blue lights on the windshield and possibly on the sides.

The automated vehicles drive in a platoon, i.e., they drive close to each other to reduce air resistance and thus save fuel. Depending on your condition, the vehicles will create different gaps for you.

We introduced the different visualization and gap concepts to the participants before each condition via printed sheets and encouraged questions. The following texts were combined depending on the condition (Translated from German):

No Visualization There is no visualization.

HUD The text “Free” is displayed on the windshield as soon as there is a gap between the vehicles.

Visualization on Vehicle There are screens on the sides of the vehicles that either tell you not to drive up here (red) or show you by arrows which gap is coming up for you. This variant could be either implemented using AR technology in the own vehicle (e.g., via a HUD) or by adding displays to the AVs, a concept currently explored in academia and industry [4, 8]. In our implementation, we envisioned displays attached to the AV.

AR The gap(s) between vehicles intended for you are displayed in green directly in the world.

Single Gap There will be one gap between the vehicles.

Multiple Gaps There will be multiple gaps between the vehicles.

After each condition, participants filled out a questionnaire with the questions outlined in Section 3.2.2. At the end of the study, participants completed a final questionnaire in which they were able to provide open-ended feedback. The study took approximately 60 min. Participants were compensated with 10€. The study was conducted in German.

3.4 Participants

We determined the required sample size via an a-priori power analysis using G*Power in version 3.1.9.7 [31]. To achieve a power of .8 with an alpha level of .05, 28 participants should result in an anticipated medium effect size (0.24 [32]) in a within-factors repeated measures ANOVA with seventeen measurements.

469 $N=29$ participants (5 female, 24 male) took part, which we recruited via mailing lists and social media. Unfortunately,
470 one participant had to be discarded because of simulation sickness, leaving us with 28 samples for the subjective data.
471 We had to discard eye-tracking and other objective data from five participants due to technical issues, leaving us with 24
472 valid datasets. As each participant experienced each condition once, this leaves us with $24 * 17 = 408$ recorded merges.
473

474 Participants had a mean age of $M=24.64$ years ($SD=2.15$, between 22 and 31 years). Every participant held a valid
475 driver's license. On average, they held the license for $M=4.86$ ($SD=0.76$) years.
476

477 Most participants (16) drove less than 7.000 km, six drove between 7.000 and 24.999 km in the past year, four between
478 25.000 and 32.999 km, one participant drove over 33.000 km, and one did not drive in the last year. One participant
479 uses a vehicle daily, one at least on weekdays, five one to four times a week, five once a week, six one to three times a
480 month, eight less than once a month, and two stated even less.

481 Immersion among the participants was medium to high ($M=19.82$, $SD=4.81$; possible range: 7 – 28).
482
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484 4 RESULTS

485 4.1 Data Analysis

486 Before every statistical test, we checked the required assumptions (e.g., normality distribution). As **no** data was normally
487 distributed, for the non-parametric data, we used the ARTool package by Wobbrock et al. [72] as the typical ANOVA is
488 not appropriate with non-normally distributed data and Holm correction for post-hoc tests. The procedure is abbreviated,
489 as in the original publication, with ART. The ART was always conducted as two-way with both communication and
490 platoon behavior as independent variables. We also included the participant as a random factor. The error bars shown
491 in Figure 3, Figure 4, Figure 5, and Figure 6, represent the bootstrapped confidence interval. R in version 4.3.2 and
492 RStudio in version 2023.09.1 was employed. All packages were up to date in December 2023. For descriptive data of
493 objective values, see Table 4.
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498 4.2 Eye Gaze Data

499 We split the eye gaze data into two subsets of areas of interest. Figure 3 clearly shows that participants focused mostly
500 on the AVs that make up the platoon. Additionally, we can see that in all scenarios but the baseline without a gap, the
501 rear mirror is looked at more than the left mirror.
502

503 Figure 4 shows the areas of interest of the communication concepts. The AR concept was consistently looked at, no
504 matter which platoon behavior was simulated. This was also the case for the eHMI. Interestingly, the HUD received
505 very few fixations in the MultiBigGaps but higher (more than double) fixations in the SingleSmallGap behavior.
506

507 We then used a Dirichlet regression. Its usage in this context is motivated by the specific nature of gaze distribution
508 data collected from participants across different scenarios. The data involves non-negative proportions that sum up
509 to one (across the areas of interest), so it qualifies as compositional data. Traditional statistical methods designed for
510 unconstrained data may lead to incorrect inferences when applied to this data type. Dirichlet regression, as suggested
511 by Hijazi and Jernigan [35], provides a more appropriate statistical approach, ensuring that the inherent constraints of
512 the data are considered. This makes it suitable for analyzing the relative contributions of different aspects within the
513 collected gaze distribution data.
514
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516 The Dirichlet regression was conducted to examine the relationship between the combined AOIs and the independent
517 variable Scenario. The analysis revealed significant effects for various scenarios across different categories of gaze
518 distribution including Null (i.e., everything but the AOIs), AV, HUD, Rear Mirror, Left Mirror, AR, and eHMI.
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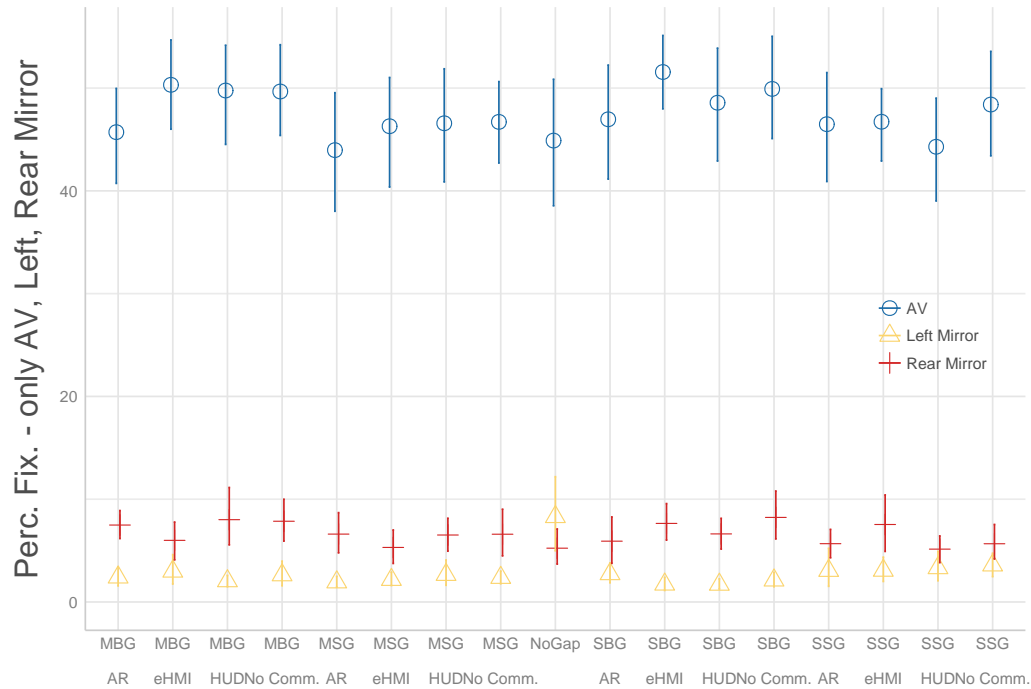


Fig. 3. Area fixations in percent (Perc. Fix. stands for Percentage fixation). SGB = SingleBigGap, MBG = MultiBigGaps, SSG SingleSmallGap, MSG = MultiSmallGaps. This figure only shows the areas AV, Left Mirror, Rear Mirror.

Specifically, the analysis showed significant beta coefficients for certain scenarios in different gaze categories. For instance, in the Null category, significant effects were observed for ScenarioMBG No Comm. ($z=2.38012, p=0.017307$), ScenarioSBG eHMI ($z=2.49110, p=0.012735$), among others.

In the AV category, significant effects were found for ScenarioMBG eHMI ($z=2.00139, p=0.04535074$), ScenarioMBG No Comm. ($z=2.55285, p=0.01068445$), and more.

Similar patterns of significant effects were also found in other categories such as HUD, Rear Mirror, and Left Mirror.

The overall model fit was satisfactory, with a log-likelihood of 7668.667 on 119 degrees of freedom and AIC of -15099.33, BIC of -14621.99. The analysis used the DirichletReg package in version 0.7.1, with a log link function and common parametrization.

4.3 Crashes, Letting Platoon Pass, and Distance to Automated Vehicles

Crashes. The ART found a significant main effect of *Communication* on Number of Crashes ($F(3, 69) = 30.22, p < 0.001$). The ART found a significant main effect of *Platoon Behavior* on Number of Crashes ($F(3, 69) = 25.44, p < 0.001$). The ART also found a significant interaction effect of *Communication* \times *Platoon Behavior* on Number of Crashes ($F(9, 207) = 3.53, p < 0.001$; see Figure 5). Interestingly, with multiple small gaps, there were more crashes than with one single gap. Participants in the baseline performed approximately as well as the communication concepts.

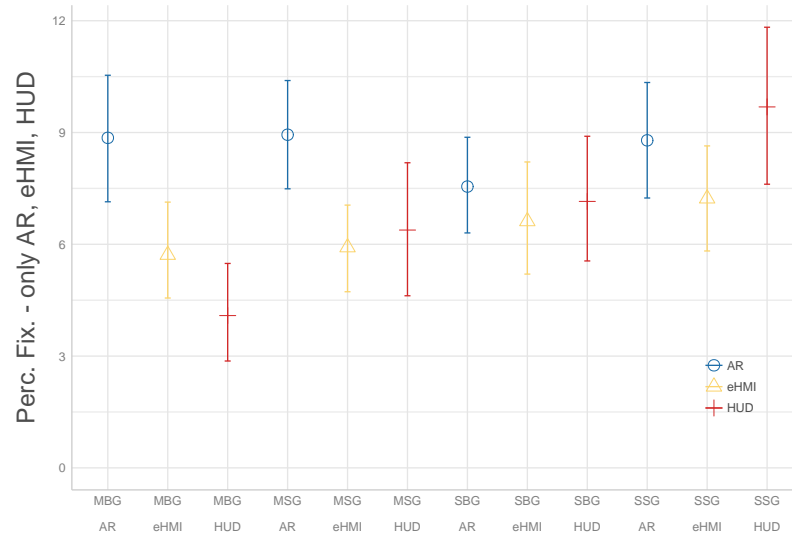


Fig. 4. Area fixations in percent. This figure only shows the areas AR, eHMI, HUD.

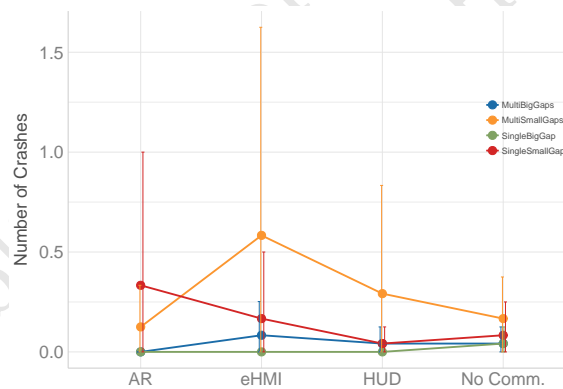


Fig. 5. Interaction effect on Number of Crashes.

Letting Platoon Pass. In all 384 recorded highway entries excluding the baseline drives, participants **never** let the entire platoon pass. In the 24 recorded baseline drives, one participant let the entire platoon pass.

Distance to Automated Vehicles. The ART found a significant main effect of *Platoon Behavior* on Distance to Front Car at Join ($F(3, 69) = 7.04, p < 0.001$). In addition, the ART found a significant interaction effect of *Communication* \times *Platoon Behavior* on Distance to Front Car at Join ($F(9, 207) = 1.97, p = 0.044$; see Figure 6a). While the large gap behaviors naturally had higher distances, the communication concepts altered these by up to 5m. In general, with AR, these were rather high. However, the HUD led to highest distances to the front car for the large gaps.

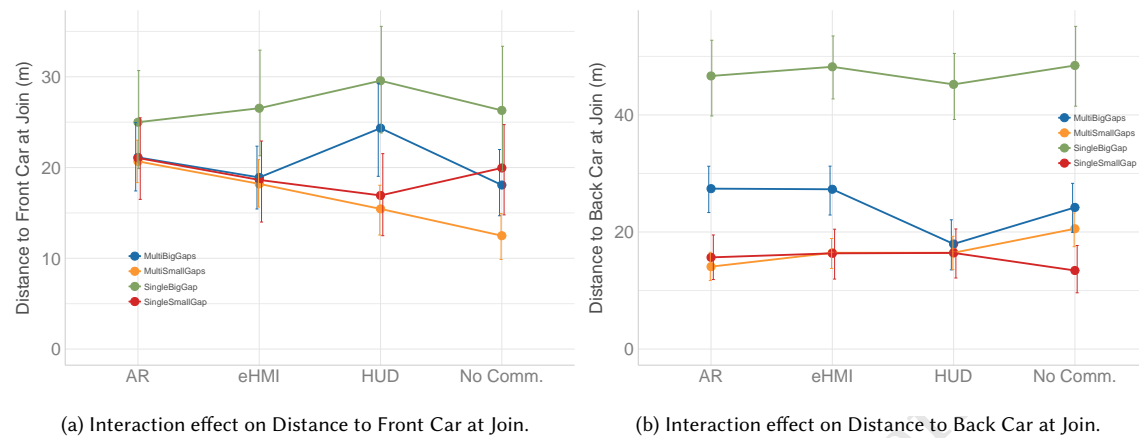


Fig. 6. Interaction effects for distances.

The ART found a significant main effect of *Platoon Behavior* on Distance to Back Car at Join ($F(3, 69) = 78.57, p < 0.001$). The ART found a significant interaction effect of *Communication* \times *Platoon Behavior* on Distance to Back Car at Join ($F(9, 207) = 2.42, p = 0.012$; see Figure 6b). For all visualizations, the single large gap led to the highest distances. For the other behaviors, there was no clear pattern discernible. However, the single small gap was always among the lowest distances.

4.4 Speed, Gap, Attempts, Time to Join, and Remained in Platoon

The ART found a significant main effect of *Platoon Behavior* on Speed at Join ($F(3, 69) = 2.81, p = 0.046$). A post-hoc test found that SingleBigGap was significantly higher ($M = 129.81, SD = 17.49$) in terms of Speed at Join compared to MultiSmallGaps ($M = 119.45, SD = 23.83; p_{adj} = 0.014$).

We also logged which gap participants joined the platoon at (see Table 1). Most participants joined in the first gap if multiple were available. However, in total, also 19 joined behind the platoon gap(s) (i.e., in the second half) and 3 before the platoon gap(s). This means that they still entered the platoon and did not jump ahead of it or let it pass entirely.

Table 1. Description of

where participants joined the platoon. One participant did not join in the condition *SSG No comm*.

| | Behind Platoon Gap(s) | Before Platoon Gap(s) | 1st gap | 2nd gap | 3rd gap | 4th gap |
|----------------|-----------------------|-----------------------|---------|---------|---------|---------|
| MultiBigGaps | 2 | 2 | 56 | 13 | 16 | 7 |
| MultiSmallGaps | 4 | 0 | 52 | 17 | 16 | 7 |
| SingleBigGap | 1 | 0 | 95 | NA | NA | NA |
| SingleSmallGap | 12 | 1 | 82 | NA | NA | NA |

Additionally, we logged the number of attempts to join the platoon (see Table 2). This was defined as the number of times that the participant switched between the acceleration lane and the highway. Most participants joined on the first attempt. However, in total, also 19 joined on the second, 2 on the third, and 1 on the fourth attempt.

Table 2. Number of attempts required to join the platoon. One participant did not join in the condition *SSG No comm*.

| | 1 | 2 | 3 | 4 |
|----------------|----|---|---|---|
| MultiBigGaps | 89 | 6 | 1 | 0 |
| MultiSmallGaps | 89 | 7 | 0 | 0 |
| SingleBigGap | 90 | 5 | 1 | 0 |
| SingleSmallGap | 93 | 1 | 0 | 1 |

The ART found a significant main effect of *Platoon Behavior* on time on acceleration lane ($F(3, 69) = 3.11, p=0.032$). A post-hoc test found that MultiSmallGaps was significantly higher ($M=5.95, SD=6.33$) in terms of *time on acceleration lane* compared to SingleBigGap ($M=4.42, SD=3.03; p_{adj}=0.041$). A post-hoc test found that SingleSmallGap was significantly higher ($M=6.91, SD=6.59$) in terms of *time on acceleration lane* compared to SingleBigGap ($M=4.42, SD=3.03; p_{adj}=0.006$).

Finally, we logged how many participants remained in the platoon at the end of each condition (see Table 3). Interestingly, most participants remained in the platoon.

Table 3. Number of participants remaining in the platoon at the end of the condition.

| | Changed Lane | Remained in Platoon |
|----------------|--------------|---------------------|
| Baseline | 4 | 20 (83.33%) |
| MultiBigGaps | 39 | 57 (59.38%) |
| MultiSmallGaps | 41 | 55 (57.29%) |
| SingleBigGap | 36 | 60 (62.50%) |
| SingleSmallGap | 30 | 66 (68.75%) |

4.5 Trust, Predictability, and Perceived Safety

Trust. The ART found a significant main effect of *Communication* on trust ($F(3, 81) = 14.50, p<0.001$). A post-hoc test found that AR was significantly higher ($M=4.00, SD=0.86$) in terms of *trust* compared to HUD ($M=3.26, SD=1.19; p_{adj} < 0.001$) and to no Communication (short: No Comm.) ($M=3.37, SD=1.14; p_{adj} < 0.001$). A post-hoc test found that eHMI was significantly higher ($M=3.89, SD=0.93$) in terms of *trust* compared to HUD ($M=3.26, SD=1.19; p_{adj} < 0.001$) and to No Comm. ($M=3.37, SD=1.14; p_{adj}=0.006$).

The ART found no significant main effect of *Platoon Behavior* ($p=0.180$) nor an interaction effect ($p=0.369$) on trust.

Predictability. The ART found a significant main effect of *Communication* on predictability ($F(3, 81) = 18.15, p<0.001$). A post-hoc test found that AR was significantly higher ($M=4.19, SD=0.70$) in terms of *predictability* compared to HUD ($M=3.59, SD=0.93; p_{adj} < 0.001$) and to No Comm. ($M=3.55, SD=0.99; p_{adj} < 0.001$). A post-hoc test found that eHMI was significantly higher ($M=4.12, SD=0.73$) in terms of *predictability* compared to HUD ($M=3.59, SD=0.93; p_{adj} < 0.001$) and to No Comm. ($M=3.55, SD=0.99; p_{adj} < 0.001$).

The ART found a significant main effect of *Platoon Behavior* on predictability ($F(3, 81) = 4.80, p=0.004$). A post-hoc test found no significant differences.

Perceived Safety. The ART found a significant main effect of *Communication* on perceived safety ($F(3, 81) = 9.05, p<0.001$). A post-hoc test found that AR was significantly higher ($M=1.56, SD=1.34$) in terms of *perceived safety* compared to HUD ($M=0.90, SD=1.53; p_{adj}=0.007$) and to No Comm. ($M=0.94, SD=1.62; p_{adj}=0.024$). A post-hoc test found that eHMI was significantly higher ($M=1.39, SD=1.54$) in terms of *perceived safety* compared to HUD ($M=0.90, SD=1.53; p_{adj}=0.049$).

The ART found no significant main effect of *Platoon Behavior* ($p=0.141$) nor an interaction effect ($p=0.267$) on perceived safety.

4.6 Task Load Index

The ART found a significant main effect of *Communication* on TLX Score ($F(3, 81) = 5.87, p=0.016$). A post-hoc test, however, found no significant differences in TLX Score.

The ART found no significant main effect of *Platoon Behavior* ($p=0.059$) nor an interaction effect ($p=0.46$) on the TLX Score.

Cognitive Workload. The ART found a significant main effect of *Communication* on cognitive workload ($F(3, 81) = 10.35, p<0.001$). A post-hoc test found that HUD was significantly higher ($M=9.64, SD=4.40$) in terms of cognitive workload compared to AR ($M=7.75, SD=4.21; p_{adj}=0.010$). A post-hoc test found that No Comm. was significantly higher ($M=10.27, SD=4.89$) in terms of cognitive workload compared to AR ($M=7.75, SD=4.21; p_{adj} <0.001$).

The ART found no significant main effect of *Platoon Behavior* ($p=0.064$) nor an interaction effect ($p=0.296$) on cognitive workload.

Physical Workload. The ART found a significant main effect of *Communication* on physical workload ($F(3, 81) = 6.04, p<0.001$). A post-hoc test found no significant differences in the physical workload.

The ART found no significant main effect of *Platoon Behavior* ($p=0.254$) nor an interaction effect ($p=0.419$) on physical workload.

Temporal Workload. The ART found a significant main effect of *Platoon Behavior* on temporal workload ($F(3, 81) = 4.28, p=0.007$). A post-hoc test found that Single Small Gap was significantly higher ($M=9.71, SD=4.92$) in terms of temporal workload compared to Multi Large Gaps ($M=7.93, SD=4.91; p_{adj}=0.020$).

The ART found no significant main effect of *Communication* ($p=0.128$) nor an interaction effect ($p=0.837$) on temporal workload.

Performance. The ART found no significant effects on performance.

Effort. The ART found a significant main effect of *Communication* ($F(3, 81) = 3.75, p=0.014$) and of *Platoon Behavior* on effort ($F(3, 81) = 3.46, p=0.020$). Post-hoc tests found no significant differences.

Frustration. The ART found no significant effects on frustration.

4.7 Situation Awareness

The ART found a significant main effect of *Communication* on situation awareness ($F(3, 81) = 13.63, p<0.001$). A post-hoc test found that AR was significantly higher ($M=5.84, SD=1.13$) in terms of *situation awareness* compared to HUD ($M=5.04, SD=1.55; p_{adj} <0.001$) and to No Comm. ($M=4.71, SD=1.72; p_{adj} <0.001$). A post-hoc test found that eHMI was significantly higher ($M=5.57, SD=1.33$) in terms of *situation awareness* compared to No Comm. ($M=4.71, SD=1.72; p_{adj} <0.001$).

The ART found a significant main effect of *Platoon Behavior* on situation awareness ($F(3, 81) = 2.95, p=0.038$). However, a post-hoc test found no significant differences.

4.8 Clarity of Behavior and Communication Quality

The ART found a significant main effect of *Communication* on behavior clarity ($F(3, 81) = 11.84, p < 0.001$). A post-hoc test found that AR was significantly higher ($M=5.96, SD=1.07$) in terms of *behavior clarity* compared to HUD ($M=5.27, SD=1.69; p_{adj}=0.031$) and to No Comm. ($M=4.91, SD=1.80; p_{adj} < 0.001$). A post-hoc test found that eHMI was significantly higher ($M=5.84, SD=1.33$) in terms of *behavior clarity* compared to No Comm. ($M=4.91, SD=1.80; p_{adj} < 0.001$).

The ART found a significant main effect of *Communication* on communication clarity ($F(3, 81) = 28.13, p < 0.001$). A post-hoc test found that AR was significantly higher ($M=6.17, SD=1.16$) in terms of *Communication clarity* compared to HUD ($M=4.48, SD=2.00; p_{adj} < 0.001$) and No Comm. ($M=4.09, SD=1.99; p_{adj} < 0.001$). A post-hoc test found that eHMI was significantly higher ($M=5.96, SD=1.32$) in terms of *Communication clarity* compared to HUD ($M=4.48, SD=2.00; p_{adj} < 0.001$) and to No Comm. ($M=4.09, SD=1.99; p_{adj} < 0.001$).

The ART found a significant main effect of *Platoon Behavior* on communication clarity ($F(3, 81) = 3.83, p=0.013$). A post-hoc test found no significant differences.

4.9 Ranking

After all the conditions, participants ranked the communication (i.e., no communication, the HUD, the display, and AR) and the behavior (no gap, single gap, multiple gaps). Friedman's ANOVAs were conducted to compare the mean rankings (lower means better). For communication, a Friedman's ANOVA showed a significant difference ($\chi^2(3)=29.53, p < .001$). Post-hoc tests showed that the AR visualization ($M=1.71$) was ranked significantly better than all other communication. The eHMI display ($M=2.00$) was ranked second and significantly better than no communication and the HUD). There was no significant difference between the HUD ($M=2.96$) and no communication ($M=3.32$).

For behavior, a Friedman's ANOVA also showed a significant difference ($\chi^2(2)=41.21, p < .001$). Post-hoc tests showed that no gap was rated significantly worse than the single gap ($M=1.32$) and the multiple gaps ($M=1.71$). There was no significant difference between single and multiple gaps, but the single gap was preferred.

4.10 Open Feedback

Participants, in general, gave positive feedback about communicating gaps. One participant proposed the combination of HUD and AR. The participants highlighted that the HUD requires perfect timing to accurately display when it is safe to merge, which they believed to be difficult. One participant also stated that it was not clear that waiting would have been a possibility for them.

5 DISCUSSION

In this work, we present an under-evaluated scenario regarding the introduction of AVs and their novel behavior, i.e., platooning. Platooning might occur at highway accesses, making it difficult for manual drivers to enter. Therefore, novel behaviors and their communication are necessary. In line with prior work in adjacent areas such as AV-pedestrian communication [7, 16, 26, 60] and bottleneck scenarios Colley et al. [11], Rettenmaier et al. [57, 58], we show the positive aspects of external communication. In addition, we found clear evidence that the AR visualization, which was modeled after previous work in takeover requests [45], was preferred.

5.1 On the Introduction of Automated Vehicles Into General Traffic

Human factors are often overlooked when designing and implementing AV concepts [1]. However, with the clear possibility of having manual drivers alongside AVs, there is a necessity to introduce concepts that enable manual drivers to be mobile safely. In this work, we also showed that despite the focus on manual drivers, crashes occurred (see Table 4). However, we showed that a human-centric evaluation can lead to **platoon behavior** and **communication** concept that lead safe human driver performance. In particular, the Single and Multi Big Gaps behavior with **any** communication led to no crashes. Instead of only looking at objective values for improving traffic efficiency, the human aspect has to be investigated even more [1]. This also becomes clear with the recent rise in studies on the communication of AVs with other, partially vulnerable road users [21, 58].

There remains the question of whether platoon behavior should, for example, automatically adapt to highway ramps by providing additional space. This could alleviate the need for human drivers to adapt their behavior, which will most likely be present for at least another 30 years (based on currently bought manual vehicles). This would lead to reduced advantages of platoon behavior regarding driving efficiency. Regarding the frequency of such a “platoon breakup”, in Germany, there are approximately 3727 (243 interchanges and more than 2,260 access points and 94 interchanges (crossings) [27], 430 managed [50], and 700 unmanaged [55] service areas) ramps for 13200 km of highway, therefore, every 3.54 km a ramp (with the longest distance being 23.9 km [71]). Therefore, platooning effectiveness would be severely reduced.

5.2 Balancing Safety and Efficiency

We introduced two different platooning behaviors with each two different distances to other AVs. Unsurprisingly, the larger distance was perceived better and led to lower crashes. The large single gap is the worst in terms of traffic efficiency, as one the AVs have to slow down the most. However, weighing the benefits and drawbacks should, in our opinion, clearly favor the safer variant. Therefore, while research on making traffic efficient is crucial, the human factor has to be included. Potentially, we tested a too-large gap. Future work could conduct a stepwise refinement to explore the parameter space (i.e., the inter-vehicle distance) to reduce the safer (and larger) distance to find a more efficient yet still safe balance.

5.3 On the Visualization Design

Our results show that the **localized** information via AR or eHMI was rated significantly better in most dependent variables. We assume that this stems from the need to quickly take in and process a lot of information. This preference is also clearly visible in the rankings. Therefore, we assume that the most important latent factor in the study design is localization of the information. Regarding the implementation of the designs, we envisioned that the technology necessary, for example, for the AR visualization, would be available. In line with previous work in the automotive domain, this AR visualization showed significant improvements [15, 18, 52], for example, for cognitive load [9]. Nonetheless, this technology is not yet available. Thus, eHMIs or even HUDs could still help make these scenarios safer. Regarding the HUD, the specific design should be then reevaluated, as the text “Free” could be cognitively more demanding than a symbol and does not provide as much information as the localized designs of eHMI and AR.

5.4 Practical Implications

This work clearly shows that platooning behavior and platoon-manual driver interaction must be considered in developing automated vehicle platoons. We show that the proposed behaviors lead to lower crashes and higher trust, which is in line with previous work in adjacent areas [11, 16, 57]. Traffic analysts, therefore, have to design platooning behavior with the user in mind. A simulation of the proposed behaviors can show which behavior is more efficient, enabling policymakers to determine the best balance between safety and efficiency. Therefore, simulations as presented by Zhou and Zhu [74] have to be updated to incorporate manual drivers.

5.5 Limitations and Future Work

A moderate number of participants took part ($N=29$). As mostly younger participants (on average, 24.62 years old) took part, it is unclear whether this work's findings are transferable to different age groups. Additionally, the participant group skewed male. We assume that in a more general population, the tendency towards less risky behavior, that is, longer gaps and clear communication, would be even stronger [39, 46, 51]. Our study participants were also all from the same cultural context, i.e., Germany. Therefore, future work should assess cultural differences for the effects of platooning. Also, transferability to real-world scenarios is difficult to assess. While much caution was given to realistically designing the scenario and reducing motion sickness symptoms, one participant had to abort due to motion sickness. The collisions also let us believe that participants would have behaved more cautiously in the real world. As the scenarios involved manually driving a vehicle, the experiment could also benefit from using simulators with higher degrees of freedom (e.g., [14] or [36]). Additionally, we assume sophisticated visualization technologies. However, our insights should be confirmed with actual capabilities and with other technology available, such as 3D display [19]. Future work should also evaluate the effect of different onramp geometries, as we expect these to have a significant effect on the merging scenario. Finally, the study took one hour, which could have led to fatigue. However, we employed counter-balancing to avoid order effects, and Schatz et al. [63] found "that even after 90 minutes of active testing, participants' quality gradings were still reliable despite the presence of measurable signs of fatigue" [63, p. 1] for auditory subjective Quality-of-Experience assessments. Therefore, we believe that the study's results are valid despite the study's length.

6 CONCLUSION

In this work, we proposed different behavior and communication concepts for platoons of AVs at highway accesses. We modeled the scenario and conducted a within-subjects study with $N=29$ participants. Our independent variables were platooning behavior (single gap or multiple gaps with different distances) and communication (AR, HUD, displays, no communication). The results of our study show that the proposed behaviors mostly improve objective and subjective measures regarding safety and trust. However, the number of crashes was also low without any communication. With multiple gaps available, these were also used by participants. The Single Large Gap and the AR communication led to the overall best results. To better understand the limits of gap sizes, future work should look more closely at stepwise refinements. This work aids the safe introduction of AVs in general traffic.

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A DESCRIPTIVE VALUES FOR OBJECTIVE DATA

| Variable | Levels | n | Min | q ₁ | \tilde{x} | \bar{x} | q ₃ | Max | s | IQR |
|-------------------------------|-------------------------|-------|-------|----------------|-------------|-----------|----------------|-------|-------|-------|
| Number of Crashes | MultiBigGaps-AR | 24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | MultiBigGaps-EHMI | 24 | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 2.00 | 0.41 | 0.00 |
| | MultiBigGaps-HUD | 24 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 1.00 | 0.20 | 0.00 |
| | MultiBigGaps-No Comm. | 24 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 1.00 | 0.20 | 0.00 |
| | MultiSmallGaps-AR | 24 | 0.00 | 0.00 | 0.00 | 0.12 | 0.00 | 2.00 | 0.45 | 0.00 |
| | MultiSmallGaps-EHMI | 24 | 0.00 | 0.00 | 0.00 | 0.58 | 0.00 | 12.00 | 2.45 | 0.00 |
| | MultiSmallGaps-HUD | 24 | 0.00 | 0.00 | 0.00 | 0.29 | 0.00 | 6.00 | 1.23 | 0.00 |
| | MultiSmallGaps-No Comm. | 24 | 0.00 | 0.00 | 0.00 | 0.17 | 0.00 | 2.00 | 0.48 | 0.00 |
| | NoGap | 24 | 0.00 | 0.00 | 0.00 | 0.50 | 0.00 | 5.00 | 1.32 | 0.00 |
| | SingleBigGap-AR | 24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | SingleBigGap-EHMI | 24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | SingleBigGap-HUD | 24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | SingleBigGap-No Comm. | 24 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 1.00 | 0.20 | 0.00 |
| | SingleSmallGap-AR | 24 | 0.00 | 0.00 | 0.00 | 0.33 | 0.00 | 8.00 | 1.63 | 0.00 |
| SingleSmallGap-EHMI | 24 | 0.00 | 0.00 | 0.00 | 0.17 | 0.00 | 4.00 | 0.82 | 0.00 | |
| SingleSmallGap-HUD | 24 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 1.00 | 0.20 | 0.00 | |
| SingleSmallGap-No Comm. | 24 | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 2.00 | 0.41 | 0.00 | |
| | all | 408 | 0.00 | 0.00 | 0.00 | 0.15 | 0.00 | 12.00 | 0.89 | 0.00 |
| Distance to Front Car at Join | MultiBigGaps-AR | 24 | 5.45 | 12.55 | 23.45 | 21.12 | 25.06 | 42.86 | 10.01 | 12.51 |
| | MultiBigGaps-EHMI | 24 | 0.00 | 14.16 | 18.25 | 18.91 | 22.79 | 38.81 | 9.16 | 8.63 |
| | MultiBigGaps-HUD | 24 | 0.00 | 17.62 | 25.25 | 24.34 | 35.34 | 42.70 | 12.86 | 17.72 |
| | MultiBigGaps-No Comm. | 24 | 0.00 | 11.79 | 15.54 | 18.07 | 25.00 | 39.07 | 9.31 | 13.21 |
| | MultiSmallGaps-AR | 24 | 9.60 | 15.42 | 21.47 | 20.68 | 25.62 | 33.10 | 6.18 | 10.20 |
| | MultiSmallGaps-EHMI | 24 | 7.64 | 14.11 | 16.69 | 18.20 | 21.36 | 31.33 | 6.71 | 7.24 |
| | MultiSmallGaps-HUD | 24 | 0.00 | 13.35 | 15.55 | 15.44 | 20.20 | 26.37 | 7.06 | 6.85 |
| | MultiSmallGaps-No Comm. | 24 | 0.00 | 8.86 | 11.74 | 12.49 | 17.44 | 21.18 | 6.18 | 8.59 |
| | NoGap | 24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | SingleBigGap-AR | 24 | 0.00 | 16.19 | 20.19 | 24.99 | 32.71 | 56.38 | 13.74 | 16.52 |
| SingleBigGap-EHMI | 24 | 7.68 | 14.15 | 25.44 | 26.53 | 30.70 | 59.41 | 14.25 | 16.54 | |
| SingleBigGap-HUD | 24 | 11.02 | 16.26 | 25.17 | 29.57 | 41.55 | 59.99 | 14.79 | 25.30 | |

| | | | | | | | | | | | |
|------|------------------------------|-------------------------|-----|--------|--------|--------|--------|--------|--------|-------|-------|
| 1145 | | SingleBigGap-No Comm. | 24 | 4.91 | 12.15 | 23.27 | 26.30 | 34.72 | 59.62 | 16.98 | 22.57 |
| 1146 | | SingleSmallGap-AR | 24 | 0.00 | 15.45 | 20.58 | 21.05 | 28.67 | 38.01 | 10.92 | 13.22 |
| 1147 | | SingleSmallGap-EHMI | 24 | 0.00 | 11.77 | 22.36 | 18.64 | 28.19 | 37.46 | 11.53 | 16.42 |
| 1148 | | SingleSmallGap-HUD | 24 | 0.00 | 11.25 | 16.49 | 16.93 | 24.42 | 37.10 | 11.32 | 13.17 |
| 1149 | | SingleSmallGap-No Comm. | 24 | 0.00 | 11.34 | 23.15 | 19.95 | 27.60 | 36.90 | 12.34 | 16.26 |
| 1150 | | all | 408 | 0.00 | 11.54 | 18.26 | 19.60 | 27.07 | 59.99 | 12.55 | 15.53 |
| 1151 | Distance to Back Car at Join | MultiBigGaps-AR | 24 | 7.11 | 23.69 | 25.98 | 27.41 | 34.79 | 44.44 | 10.01 | 11.10 |
| 1152 | | MultiBigGaps-EHMI | 24 | 0.00 | 21.37 | 28.99 | 27.30 | 34.23 | 44.79 | 10.70 | 12.86 |
| 1153 | | MultiBigGaps-HUD | 24 | 0.00 | 8.93 | 16.44 | 17.95 | 27.96 | 40.45 | 11.16 | 19.03 |
| 1154 | | MultiBigGaps-No Comm. | 24 | 0.00 | 17.81 | 23.83 | 24.20 | 30.78 | 41.06 | 10.64 | 12.97 |
| 1155 | | MultiSmallGaps-AR | 24 | 1.76 | 9.28 | 13.32 | 14.08 | 19.63 | 25.14 | 6.33 | 10.35 |
| 1156 | | MultiSmallGaps-EHMI | 24 | 3.59 | 12.53 | 18.21 | 16.45 | 20.79 | 27.23 | 6.73 | 8.26 |
| 1157 | | MultiSmallGaps-HUD | 24 | 0.00 | 12.48 | 18.25 | 16.45 | 21.00 | 31.32 | 7.26 | 8.52 |
| 1158 | | MultiSmallGaps-No Comm. | 24 | 0.00 | 16.81 | 20.95 | 20.55 | 25.80 | 33.02 | 7.18 | 8.99 |
| 1159 | | NoGap | 24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1160 | | SingleBigGap-AR | 24 | 0.00 | 41.12 | 51.25 | 46.66 | 57.44 | 66.41 | 16.14 | 16.33 |
| 1161 | | SingleBigGap-EHMI | 24 | 15.18 | 44.20 | 49.43 | 48.23 | 60.43 | 67.06 | 14.25 | 16.23 |
| 1162 | | SingleBigGap-HUD | 24 | 14.86 | 33.19 | 49.49 | 45.22 | 58.60 | 63.79 | 14.82 | 25.41 |
| 1163 | | SingleBigGap-No Comm. | 24 | 15.24 | 39.94 | 51.35 | 48.45 | 62.72 | 69.94 | 16.97 | 22.78 |
| 1164 | | SingleSmallGap-AR | 24 | 0.00 | 8.16 | 16.95 | 15.66 | 22.11 | 33.05 | 10.04 | 13.95 |
| 1165 | | SingleSmallGap-EHMI | 24 | 0.00 | 9.59 | 15.58 | 16.35 | 25.35 | 37.92 | 11.03 | 15.76 |
| 1166 | | SingleSmallGap-HUD | 24 | 0.00 | 4.77 | 21.43 | 16.42 | 24.40 | 35.47 | 11.19 | 19.62 |
| 1167 | | SingleSmallGap-No Comm. | 24 | 0.00 | 3.95 | 13.57 | 13.42 | 19.62 | 31.10 | 10.31 | 15.67 |
| 1168 | | all | 408 | 0.00 | 12.33 | 21.66 | 24.40 | 33.38 | 69.94 | 17.65 | 21.05 |
| 1169 | Speed at Join | MultiBigGaps-AR | 24 | 76.88 | 104.76 | 119.76 | 121.54 | 136.04 | 174.15 | 21.93 | 31.28 |
| 1170 | | MultiBigGaps-EHMI | 24 | 26.77 | 118.38 | 126.39 | 124.21 | 136.62 | 163.89 | 25.90 | 18.24 |
| 1171 | | MultiBigGaps-HUD | 24 | 98.02 | 117.22 | 127.59 | 129.34 | 139.60 | 160.26 | 16.66 | 22.37 |
| 1172 | | MultiBigGaps-No Comm. | 24 | 32.95 | 112.23 | 123.31 | 119.37 | 134.45 | 150.82 | 23.32 | 22.22 |
| 1173 | | MultiSmallGaps-AR | 24 | 45.56 | 115.29 | 128.23 | 121.35 | 136.03 | 149.63 | 23.90 | 20.74 |
| 1174 | | MultiSmallGaps-EHMI | 24 | 58.53 | 113.55 | 123.45 | 121.58 | 131.46 | 155.10 | 20.12 | 17.92 |
| 1175 | | MultiSmallGaps-HUD | 24 | 37.52 | 113.59 | 125.00 | 116.66 | 130.90 | 165.41 | 28.89 | 17.31 |
| 1176 | | MultiSmallGaps-No Comm. | 24 | 38.00 | 109.85 | 124.78 | 118.19 | 131.94 | 143.15 | 22.74 | 22.09 |
| 1177 | | NoGap | 24 | 0.17 | 54.61 | 64.69 | 71.72 | 98.45 | 133.28 | 34.07 | 43.85 |
| 1178 | | SingleBigGap-AR | 24 | 69.51 | 122.99 | 131.85 | 128.11 | 136.21 | 174.20 | 20.45 | 13.22 |
| 1179 | | SingleBigGap-EHMI | 24 | 103.75 | 123.19 | 131.02 | 130.14 | 134.31 | 162.05 | 12.62 | 11.12 |
| 1180 | | SingleBigGap-HUD | 24 | 95.34 | 122.72 | 129.40 | 132.33 | 143.13 | 168.64 | 18.14 | 20.41 |
| 1181 | | SingleBigGap-No Comm. | 24 | 82.46 | 122.62 | 131.66 | 128.69 | 140.25 | 158.60 | 18.59 | 17.62 |
| 1182 | | SingleSmallGap-AR | 24 | 39.93 | 118.51 | 133.06 | 130.43 | 145.04 | 172.39 | 24.86 | 26.53 |
| 1183 | | SingleSmallGap-EHMI | 24 | 21.23 | 114.52 | 126.58 | 115.79 | 134.80 | 158.49 | 33.90 | 20.28 |
| 1184 | | SingleSmallGap-HUD | 24 | 20.57 | 106.33 | 127.24 | 115.75 | 140.10 | 150.58 | 34.01 | 33.77 |
| 1185 | | SingleSmallGap-No Comm. | 24 | 0.00 | 120.25 | 128.40 | 124.52 | 141.01 | 180.83 | 37.63 | 20.77 |
| 1186 | | all | 408 | 0.00 | 113.58 | 126.42 | 120.57 | 135.57 | 180.83 | 28.33 | 21.99 |
| 1187 | Time on Acceleration lane | MultiBigGaps-AR | 24 | 2.23 | 4.34 | 5.88 | 5.80 | 6.79 | 9.21 | 2.10 | 2.45 |
| 1188 | | MultiBigGaps-EHMI | 24 | 1.88 | 3.15 | 3.67 | 5.38 | 5.68 | 23.67 | 4.52 | 2.52 |
| 1189 | | MultiBigGaps-HUD | 24 | 1.51 | 3.48 | 3.93 | 4.07 | 4.54 | 6.69 | 1.20 | 1.06 |
| 1190 | | MultiBigGaps-No Comm. | 24 | 2.25 | 3.11 | 3.41 | 4.75 | 5.04 | 21.57 | 3.88 | 1.93 |
| 1191 | | MultiSmallGaps-AR | 24 | 2.12 | 3.44 | 5.03 | 7.08 | 6.68 | 55.32 | 10.49 | 3.25 |
| 1192 | | MultiSmallGaps-EHMI | 24 | 2.15 | 3.26 | 4.00 | 4.58 | 5.71 | 9.41 | 2.01 | 2.45 |
| 1193 | | MultiSmallGaps-HUD | 24 | 1.28 | 3.72 | 4.85 | 6.30 | 7.18 | 23.54 | 5.45 | 3.45 |
| 1194 | | MultiSmallGaps-No Comm. | 24 | 2.12 | 3.77 | 4.55 | 5.83 | 6.65 | 23.39 | 4.26 | 2.88 |
| 1195 | | NoGap | 24 | 3.53 | 11.13 | 24.08 | 20.27 | 26.82 | 32.82 | 8.64 | 15.68 |
| 1196 | | SingleBigGap-AR | 24 | 1.58 | 2.64 | 3.78 | 5.03 | 6.55 | 25.99 | 4.95 | 3.91 |
| 1197 | | SingleBigGap-EHMI | 24 | 1.36 | 2.64 | 3.60 | 3.80 | 4.39 | 8.53 | 1.66 | 1.75 |
| 1198 | | SingleBigGap-HUD | 24 | 1.00 | 2.50 | 3.85 | 4.52 | 6.55 | 9.55 | 2.53 | 4.05 |
| 1199 | | SingleBigGap-No Comm. | 24 | 1.48 | 3.28 | 4.21 | 4.33 | 4.95 | 9.25 | 1.86 | 1.67 |

| | | | | | | | | | | |
|------|-------------------------|-----|------|------|------|------|------|-------|------|------|
| 1197 | SingleSmallGap-AR | 24 | 1.70 | 3.83 | 4.90 | 5.54 | 5.35 | 27.89 | 4.95 | 1.52 |
| 1198 | SingleSmallGap-EHMI | 24 | 1.14 | 3.46 | 4.68 | 7.47 | 7.02 | 26.59 | 7.34 | 3.56 |
| 1199 | SingleSmallGap-HUD | 24 | 0.95 | 3.75 | 5.08 | 7.10 | 6.29 | 26.28 | 6.81 | 2.54 |
| 1200 | SingleSmallGap-No Comm. | 24 | 2.04 | 3.57 | 5.32 | 7.52 | 7.16 | 26.84 | 7.22 | 3.59 |
| 1201 | all | 408 | 0.95 | 3.27 | 4.42 | 6.43 | 6.60 | 55.32 | 6.41 | 3.33 |

Table 4. Descriptive data for objective data.

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