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On Optimizing Driving Patterns of Autonomous Cargo Bikes as a Function of Distance and Speed—A Psychological Study

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ABSTRACT It is predicted that the number of autonomous vehicles will increase in the forthcoming years. In this context, this research deals with autonomous micro-mobiles, specifically autonomous cargo bikes. In the development of (partially) autonomous vehicles, it is important to consider the safety perspective of vulnerable road users, such as pedestrians, already during development to enhance acceptance and widespread use. We investigated the safety parameters of speed and distance. For this purpose, videos with varying distance and speed parameters were filmed from a third-person perspective. These were then distributed via online questionnaires and evaluated by subjects regarding the subjective perceived safety. The results show that perceived safety increases with increasing passing and yielding distance and decreasing passing speed. Even at very short distances and relatively high speeds, the behavior of the cargo bike was still considered safe. These results can serve as reference values in the development of autonomous micro-mobiles. Further, the high safety perception should encourage planners and decision-makers to give these technologies a chance and boldly tackle the mobility revolution and test possible substitutes for motorized individual transport.

INDEX TERMS Autonomous micro-mobility, perceived safety, urban mobility solutions, video-supported study.

I. INTRODUCTION: AN INTELLIGENT AUTONOMOUS MICRO-MOBILITY OFFER

THE MOBILITY sector is changing and is currently characterized by technological innovations, especially in the field of autonomous mobility or autonomous micro mobiles [1]. This is in line with similar changes in the energy or housing sector inspired by sustainability goals so that a transformation of society as a whole is supported, see also [2]. In the field of autonomous innovation, there is currently a lot of research on autonomous cars, e.g., [3], but also autonomous shuttle buses or other additions to public transport, e.g., [4], [5], [6]. Although risks and questions of trust in such technologies seem to dominate the public discourse [7], autonomous micro mobiles in particular offer a wide range of social opportunities. Especially from a sustainability perspective, the replacement of cars should be mentioned here, which not only goes hand in hand with a reduction of fuels and CO2 emissions [8], [9] but also offers improvements in terms of the number of road crashes and accidents [10] and general road safety [11].

The ERDF-funded research project "AuRa" is dedicated to the development of such an autonomous micro mobile that is integrated into a sharing system. More precisely, a three-wheeled, autonomous cargo bike is to be developed that

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can ride autonomously on existing bike lanes and obeys the legal traffic rules. Its field of application is, for example, access to public transport or bridging the last mile, for transport purposes in urban settings such as shopping, load transport, child transport, or for pedalling support for common cycle lanes for users with limited mobility, see also [12], [13], [14]. Thus, the autonomous cargo bike could significantly promote door-to-door mobility and solve common problems of conventional bike-sharing systems, such as fleet imbalances during peak hours [15], [16]. Our interdisciplinary research focuses not only on the technical realization of such an autonomous cargo bike, but also on how it should behave in daily contact with pedestrians, other cyclists, or car drivers. In its autonomous state, the bike can move and navigate on its own. Thus, it is particularly relevant to determine which distances, speeds, and movements of the cargo bike are perceived as safe as possible since past experiences with autonomous vehicles tend to shape attitudes towards and acceptance of such an unfamiliar technology. The fact that autonomous vehicles are not only expected to guarantee safety but are measured against other standards than vehicles maneuvered by humans adds even more relevance [17], [18]. As studies have suggested, perceived safety is of fundamental importance for the acceptability of such mobility offers and the value that is ascribed to them socially [1], [5], [19], [20]. In traffic situations, perceived safety can be defined as a subjective measurement of safety and denotes the perceived extent of the risks of injury or materialistic loss [21]. Particularly from a psychological perspective, it is relevant to depict the subjective part of safety. Such assessments are often made by individuals under the influence of their personality, situational aspects, and previous experiences and take place in a context of social, but also environmental factors (for an overview, see [22] or more precisely [23], [24]). The primary aim of this study, therefore, is not to make objective statements about the safety of a technical system such as the autonomous cargo bike, but to find out how safe people perceive it to be when interacting with them.

II. THEORY

In the ever-growing research on interaction with and interface design of autonomous mobiles, e.g., [25], [26], there is increasing interest in how particularly vulnerable groups can be adequately accommodated in road transport and their needs can also be met by driverless mobiles [27], [28], [29], [30]. This research is relevant as it can have a significant impact on the acceptability of autonomous mobility - which can give more context to current media reports such as accidents involving autonomous cars. However, much of this research, as well as media reports, relates to autonomous cars and may focus on the phase when people are sitting in and using an autonomous mobile, e.g., [25], [31] or hypothetical extreme situations, in which an autonomous vehicle faces a moral dilemma to choose between two undesirable options [32], [33]. Thus, our approach is unique as it focuses on the interaction with a driverless micro mobile (i.e. it drives without passengers) in everyday traffic situations. Being able to adequately design the interaction of an autonomous micro vehicle is important for its safety. Thus, the ideal system operation should be pre-programmed in the best possible way. However, even in an ideal system operation, such as state-of-the-art sensor functionality (e.g., see [34]), interactions should be pre-programmed in the best possible way. For autonomous cars or buses, for example, projections that hint at the path are being researched for this purpose [26], [27]. An autonomous cargo bike cannot use this option, but can only communicate its intentions via more classical communication channels, such as a ringing bike bell, smaller display icons, or lighting signals [35]. In contrast to studies on communication strategies of autonomous vehicles, which are optimized to ensure secure driving interactions [36], there has been little research on how spatial driving characteristics of driverless micro mobiles affect perceived safety. Since the interactions between pedestrians and the cargo bike will mostly occur on shared sidewalks, not on roads, these will be our focus.

To determine their future trajectories, automated vehicles rely on a motion planning subsystem. Regardless of the specific algorithm used therein, the motion planning problem is usually an optimization in which some numeric measure of quality is used to determine the best future action of the autonomous vehicle for the current situation [37]. This numeric measure is often referred to as a cost function and usually comprises several possibly conflicting goals. To integrate the perceived safety of other traffic participants into any motion planning algorithm, we need to be able to numerically quantify that perception to integrate into the algorithm's cost function.

To assess perceived safety (or risk indicators) for road interactions, numerous approaches have been employed (see [38] for an overview). While most approaches focus on objective measurements, such as the time-to-collision (TTC), performance index for approach and alienation, time-headway, and risk feeling [39], subjective approaches are sparse. We would like to emphasize, especially from a psychological perspective, why subjective safety perceptions and assessment may not only be of equal importance but even more significant. As, e.g., [38] argue, the subjective perspective plays a greater role in an appropriate assessment of acceptance - and thus later use. Especially with innovative micro mobiles, like the autonomous cargo bike we studied, interaction with pedestrians or other cyclists takes place in a much narrower, unbounded space. Therefore, it is not only a matter of calculating theoretically and objectively, e.g., TTC, but of testing at what point an interaction is judged to be no longer safe (regardless of whether physically safe braking would still have been possible). A situation that is theoretically safe but not perceived as such can lead to negative feelings and stress, which should be avoided. Conversely, it is also important to note that an objectively unsafe situation can also be perceived as safe subjectively, leading to a risk of an accident [38]. Focusing on pedestrians, apart from direct communication with vehicles - or their occupants, should there be any - usually consider the distance and speed of a (autonomous) vehicle [25], [40]. Especially in sidewalk interactions, studies have identified passing speed [41], passing distance [38], [42], and the distance to a pedestrian when the path of an autonomous vehicle crosses the path of the former, requiring the latter to yield [43], as factors for perceived safety. However, this research was conducted on human-driven mobility vehicles, specifically *Segways* and bicycles, thus results are not fully generalizable to autonomous vehicles. Even though autonomous vehicles must adhere to the same regulations as human drivers and are programmed to do so, this does not equate to guaranteed perceived safety [38]. This is especially true for vulnerable road users, like pedestrians [44]. For example, imagine a situation where a vehicle passes close to a pedestrian at high speed. Although the person is not injured and the situation is objectively safe, it may be perceived as less safe by observers and the person themselves. Further, it is self-evident that higher distances and lower speeds lead to a higher perception of safety, as confirmed in previous studies, e.g., [38]. However, it is not reasonable for the intended use of an autonomous cargo bike, and micro mobiles in general, if they only drive at night, slowly, and at great distances in order not to encounter pedestrians. If purposeful use is to be ensured, frequent human-technology interactions are unavoidable. Therefore, apart from confirming the expected relation between speed, distance (passing and yielding), and perceived safety, it is crucial to establish whether there are minimum distances (passing and yielding) or maximum speeds that are no longer judged to be safe by observers; in other words what distances and speeds are amenable to people. We hypothesize that the more distance an autonomous cargo bike keeps, when passing a pedestrian (H1a), the slower it passes (H1b) and the more distance it keeps when yielding (H1c), the safer it is perceived. Further, we include a non-directive exploratory analysis to investigate what speed and distances are not considered to be safe anymore.

The investigation of the interaction of an autonomous cargo bike with its environment poses another scientific challenge: the vehicle is currently still under development and can hardly be encountered in daily situations. Thus, an indirect experimental setup is necessary. Previous studies have relied on VR for this purpose [13], [25] or have chosen to illustrate different traffic interactions and to distribute them via online questionnaires, e.g., [45]. In this indirect observation, it is all the more relevant to choose both robust and unambiguous situations so that judgments made by study participants are distorted as little as possible. It is therefore generally desirable to design situations as realistic as possible to allow study participants to put themselves in different situations as easily as possible. We, therefore, took the approach of recording short videos of various

FIGURE 1. Screenshot from the Survey.

traffic interactions between pedestrians and the autonomous cargo bike.

III. METHODS

A. SAMPLE

Out of the 505 persons who started the survey, 101 turned out to be valid cases (missing values $\leq 6\%$ and completed all relevant pages; rate: 20%). Out of these 101 valid cases, five were excluded due to implausibly fast completion of the survey [46], one due to crucial missing data, and nine due to failure of answering a control item correctly [47]. The final sample consists of $N = 86$ (53% female, 43% male, and 1% divers) participants aging between 20 and 64 years ($M = 29.65$, $SD = 10.92$). The participants were recruited via Facebook groups, the online e-mailing list of the IPU (*Initiative Psychologie im Umweltschutz*) [48] and among students of the University of Magdeburg.

B. EXPERIMENTAL PROCEDURE

All participants went through the same online study using a within-subject design, created with SoSci Survey [49]. The survey could be accessed and completed by participants on their own devices such as laptops, PCs and smartphones. Figure 1 shows a screenshot of a questionnaire page on which one of the videos was played, with an excerpt of the questions below.

After information about the generic purpose of the project socio-demographic data was assessed. In the actual study, participants were asked to watch in total 18 short videos of around 6 seconds demonstrating different interaction scenarios between an autonomous cargo bike and a female/male pedestrian (for a detailed description see Section III-C, this chapter). To verify that the devices of the participants met the technical requirements to correctly replay the videos, a test clip was played. Subsequently, the participants were asked to answer a test question, which could only be answered if the video was played correctly. An incorrect answer led to exclusion. The remaining participants watched all videos within one session and, on average, took *M* J 9.51, *SD* = 2.52 minutes to complete the entire questionnaire. The viewing order of the videos was randomized in blocks to avoid sequence effects [50]. Following each of the 18 videos, participants were asked to rate the just displayed situation in terms of the safety of the cargo bike's behavior. At the end of the study participants from Magdeburg, Germany, the project's home base, were additionally asked how they felt about a hypothetical introduction of autonomous cargo bikes in their city (*acceptability*). However, since only nine participants answered this item it was omitted from further analysis. After completing the entire questionnaire, participants were thanked for their participation, received additional information about the study and had the opportunity to leave their contact details should they wish to be informed of its results.

C. SCENARIOS

Three different interaction scenarios (see Figure 2), each containing three situation variations, between a pedestrian and the autonomous cargo bike were professionally filmed with the help of the media competence center of the University of Magdeburg. Since the cargo bike is still under development, the piloting had to be done manually. Scenarios 1 and 2 were filmed in such a way that it appeared to the viewer as if they were seeing the situation themselves. To ensure this, the videos were filmed from a height of circa 170cm, with the average height in Germany being 166cm for women and 180cm for men [51]. The virtual distance to the place of interaction was 300-350cm. Scenario 3 was shot from a closer and deeper perspective (about 100cm height and 150-200cm distance) to better visualize the different yielding distances. Previous studies have used similar third-person evaluations successfully, to study pedestrian-bike interaction [42]. In scenario one, the bike passed a walking pedestrian with a constant speed of $v = 12$ km/h, thus around the average cyclist speed in Germany of 13.9 km/h [52], while varying its distance from $d = 50$cm to 110cm. Although bicycles must always be considerate towards pedestrians [53], the duty of care is fulfilled with a distance of 75-80cm according to the German Federal Court [54], which is why this distance represents the middle category. In scenario two the cargo bike varied its speed from $v = 5$ km/h to $v = 15$ km/h while keeping a steady distance of $d = 80$ cm from a standing pedestrian. In scenario three the cargo bike yielded at a varying distance of 50cm to 110cm in front of a pedestrian standing on the bike lane part of the sidewalk. The cargo bike approached at a speed of $v = 5$ km/h to then halt in a brake at the desired distance (deceleration rate $a = -2.4$ m/s^2). The breaking points were determined in pre-tests. Since the cargo bike does not yet drive autonomously with sensors, but was controlled manually, a higher approach speed could unfortunately not be realized, to avoid endangering the pedestrian

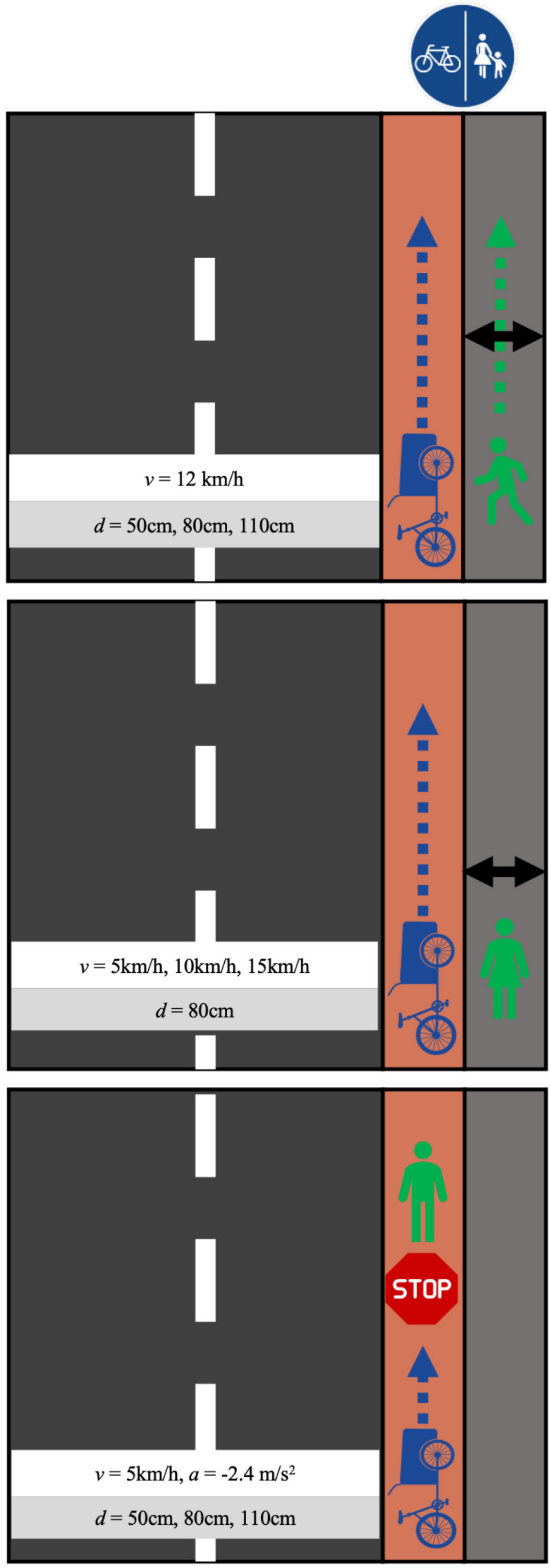


FIGURE 2. Scenarios 1-3.

actors. This scenario is also aligned with the ruling of the German Federal Court that the duty to care for pedestrians also applies to marked bicycle paths [53]. The situation was

TABLE 1. Item list of the safety scale, translated to english.

Number	Content
1	*I estimate the risk of injury to the pedestrian to be low.*
2	*I feel this situation is safe for the pedestrian.*
3	*The autonomous cargo bike behaves appropriately in this situation.*
4	*The autonomous cargo bike shows sufficient consideration for the pedestrian.*
5	*The autonomous cargo bike behaves politely.*
6	*I feel that this situation is dangerous for the pedestrian.*

filmed in such a way that the viewer could suspect that the pedestrian was not fully aware of the approaching vehicle. There was one version of each video with a female and a male protagonist, to ease participants' identification.

D. MEASURES

We used 6 items to measure safety, which were to be answered on a 5-point Likert scale (*completely disagree - rather disagree - undecided - rather agree - completely agree*). Likert scales are a convenient, easy, and straightforward way to collect responses [55]. Based on items used in previous work [25], [40], [43], we formulated items to measure perceived safety in the displayed scenarios (see Table 1). These items were aggregated to form a safety scale. Further, we calculated an individual person index for each participant, one for every situation. Prior, we investigated if the gender of the protagonist in the videos influenced the safety rating of the participants. No systematic gender differences were found. Thus, the person index was created by calculating the sum score over all items of the safety scale and combining the ratings for both gender variations of the videos (theoretically possible range 0 - 60). Mean Cronbach's alpha was $\alpha = 0.92$ (range: $\alpha = 0.90$ - 0.95, $SD = 0.02$), validating the reliability over all 18 applications of the scale.

E. ANALYSIS APPROACH

Analysis was conducted in RStudio (version 1.4.1106) and Microsoft Excel (version 16.58). R-packages used are car [56], cocor [57], data.table [58], extrafont [59], Himsc [60], ltm [61], psych [62], tidyverse [63], rstatix [64], skimr [65], and varhandle [66]. Repeated-measure-ANOVAs (analysis of variance), see [67], combined with pairwise comparisons with bonferroni corrections (H1a-c) and one-sample *t*-tests (exploratory analysis) are applied to the data for hypothesis testing. Effect sizes for pairwise comparisons (Hedge's g_{av}) were calculated with the Excel spreadsheet

TABLE 2. Results for repeated-measure ANOVA and respective pairwise comparison tests.

	Scenario 1		Scenario 2		Scenario 3	
	M	*SD*	*M*	*SD*	*M*	*SD*
Situation 1	51.0	9.4	53.5	7.5	41.8	8.6
Situation 2	47.9	10.4	49.5	9.1	48.7	9.4
Situation 3	44.1	11.6	45.5	11.1	43.9	11.2
ANOVA	$F(1.34,113.61) = 31.89$*		$F(1.52,129.32) = 93.01$*		$F(1.65,140.45) = 66.77$*	
PWC	*t*	*Hedge's* g_{av}	*t*	*Hedge's* g_{av}	*t*	*Hedge's* g_{av}
1 vs. 2	5.47*	0.34 [-0.40, 1.08]	6.11*	0.47 [-0.27, 1.22]	5.47*	0.34 [-0.40, 1.08]
1 vs. 3	9.86*	0.65 [-0.14, 1.44]	8.38*	0.83 [0.01, 1.65]	9.86*	0.78 [-0.08, 1.64]
2 vs. 3	7.85*	0.35 [-0.42, 1.11]	6.82*	0.39 [-0.38, 1.16]	7.85*	0.46 [-0.32, 1.24]

Note. PWC = pairwise comparison test; * = $p < .001$; square bracket is the 95% confidence interval for Hedge's g_{av}

provided by [68]. In general Hedge's g_{av} between 0.2 and 0.5 is commonly interpreted as a small, Hedge's g_{av} between 0.5 and 0.8 as a medium and Hedge's g_{av} over 0.8 as a large effect [69].

IV. RESULTS

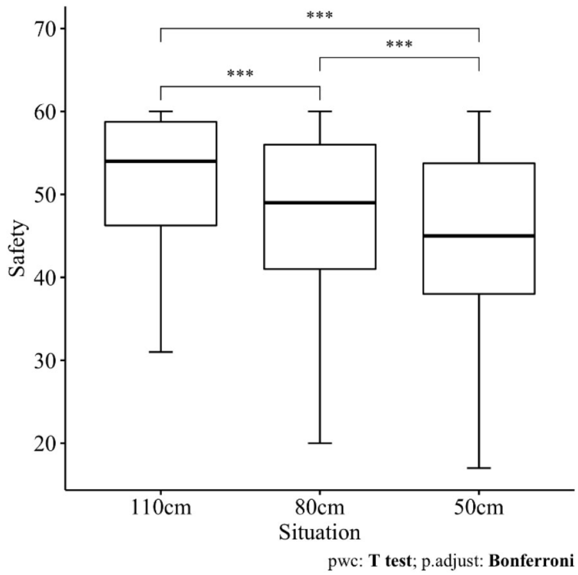
In this section results of the statistical analyses conducted are reported, ordered by scenario. The results are displayed in Table 2.

A. SCENARIO ONE

A repeated-measure-ANOVA was conducted to test the research hypothesis that perceived safety decreases with decreasing passing distance. As expected the ANOVA returned significantly. Pairwise comparisons using the *p*-value bonferroni adjustment ($p = 0.017$) revealed significant differences for all three pairwise comparisons. Specifically, a passing distance of 110cm was considered significantly safer than a passing distance of 80cm or 50cm. 80cm in turn was perceived significantly safer than 50cm (see Table 2 and Figure 3). These results support H1a.

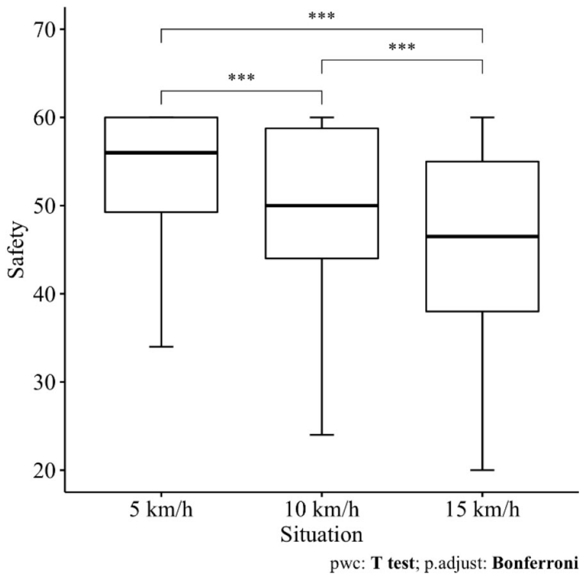
B. SCENARIO TWO

A repeated-measure-ANOVA was conducted to test the research hypothesis that perceived safety decreases with increasing passing speed. As expected the ANOVA returned significantly. Pairwise comparisons using *p*-value bonferroni adjustment ($p = 0.017$) revealed significant differences for all



Note. * = $p < .05$; ** = $p < .01$; *** = $p = < .001$

FIGURE 3. Repeated-measures-ANOVA for scenario one.



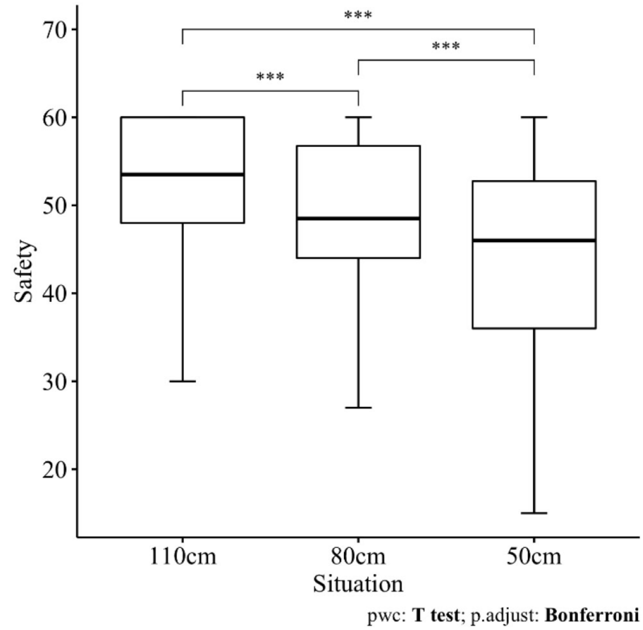
Note. * = $p < .05$; ** = $p < .01$; *** = $p = < .001$.

FIGURE 4. Repeated-measures-ANOVA for scenario two.

comparisons. Specifically, a passing speed of 5km/h was considered significantly safer than a passing speed of 10km/h or 5km/h. 10km/h in turn was perceived significantly safer than 5km/h (see Table 2 and Figure 4). These results support H1b.

C. SCENARIO THREE

A repeated-measure-ANOVA was conducted to test the research hypothesis that perceived safety decreases with reducing yielding distance. As expected the ANOVA returned significantly. Pairwise comparisons using the *p*-value bonferroni adjustment ($p = 0.017$) revealed significant



Note. * = $p < .05$; ** = $p < .01$; *** = $p = < .001$.

FIGURE 5. Repeated-measures-ANOVA for scenario three.

differences for all comparisons. for all three pairwise comparisons. Specifically, a yielding distance of 110cm was considered significantly safer than a yielding distance of 80cm or 50cm. 80cm in turn was perceived significantly safer than 50cm (see Table 2 and Figure 5). These results support H1c.

D. PERCEIVED SAFETY IN CLOSE/ HIGH-SPEED SITUATIONS

We aimed to explore if there was any speed or distance between the cargo bike and the pedestrian within the boundaries we set that would cause the cargo bike to be judged as unsafe. When screening the data, we encountered seemingly high perceived safeties. Thus, we decided to investigate the closest and highest speed situations only to reduce redundancy. The test value against which we tested the data was 30 points on the safety scale. This represents the value a participant would receive if they had always chosen to mark the option *undecided* on the safety scale. Thus, it represents a *neutral* score, i.e., neither unsafe nor safe. For scenario one situation 3 ($M = 44.1$, $SD = 11.6$), which represents the closest passing distance, was perceived significantly safer than neutral ($\mu = 30$), $t(85) = 11.3$, $p < 0.001$, Cohen's $d = 1.21$ 95% CI[0.94, 1.56]. For scenario two situation 3 ($M = 45.5$, $SD = 11.1$), which represents the highest passing speed, was also perceived significantly safer than neutral ($\mu = 30$), $t(85) = 12.9$, $p < 0.001$, Cohen's $d = 1.39$ 95% CI[1.12, 1.74]. Finally situation 3 ($M = 43.9$, $SD = 11.2$), which represents the closest halting distance, in scenario three was perceived significantly safer than neutral ($\mu = 30$), $t(85) = 11.6$, $p < 0.001$, Cohen's $d = 1.25$ 95% CI[0.97, 1.62].

V. DISCUSSION

Perceived safety is one of the driving factors for the acceptance of new mobility technologies [1], [5], [20]. In this study, we set out to explore how the speed of an autonomous cargo bike and its passing and yielding distance influence the perceived safety in pedestrian interactions. As expected the situations which were objectively the safest, meaning the slowest and the one ensuring the most distance between the pedestrian and the cargo bike were also perceived as the safest. Interestingly, we were able to determine that even in the most extreme of the tested situations, the cargo bike was deemed safe. This was true for the closest drive-by distance, the highest drive-by speed, and the nearest yielding distance.

Within the present sample and the tested situations, we assume that the bike's driving behavior, concerning the assessed speed and distance dimensions, was generally perceived as safe. Even distances that fall below the legal standard of care were designated as safe. One of the causes for the overall safety rating of the situations shown might be that humans are generally quite skilled at estimating braking distances and speed at low, but not at high tempo [70]. While this is good news for relatively slow-moving micro mobiles, such as the tested autonomous cargo bike, it nevertheless indicates that the present results cannot necessarily be applied to higher speeds of other vehicles. Further, the present results regarding speed and distance fit well with recent findings, which suggest that from the perspective of pedestrians, automated vehicles pose a lower perceived risk than human-driven vehicles [20], [71]. The present study does not include a comparison between human- and machine-driven vehicles, which may limit the comparability to some extent. A follow-up study could provide clarity here. Most surprising was that even in scenario 3, where a collision risk was most probable as the pedestrian was on the path of the cargo bike, all situations were rated as at least rather safe. In previous studies, it was shown that the safety perception of pedestrians decreases with increasing driving speed, e.g., [72]. Furthermore, it was shown that a higher deceleration rate facilitates the perception of a braking event, which is important for informal communication between autonomous vehicles and pedestrians and thus also for safety [73]. Hence, the relatively high safety perception of scenario 3 can be explained by the fact that breaking was executed at low speed.

For transporting goods, most people in WEIRD countries still rely on their cars, e.g., [74]. Micro mobiles, such as the autonomous cargo bike, can help reduce the use of cars on these trips (e.g., for groceries shopping), thus avoiding congestion and saving CO_2 emissions. Moreover, their availability would be a step towards mobility equity, if they were made available to more people [75]. In light of the ongoing public discourse about the safety of such mobility solutions [7], the present study was able to show that the autonomous cargo bike is, at reasonable distances and speeds, indeed considered safe in shared spaces. Taken together, the present results should be encouraging tidings for policymakers, regulatory agencies, engineers, as well as practitioners who are uncertain about societal safety assessments. We believe that this can be a good selling point for the introduction of autonomous cargo bikes.

VI. LIMITATIONS AND FUTURE RESEARCH

Regarding the current study, some limitations need to be mentioned which can be considered in future research. Firstly, it should be noted that throughout the study the subjects were asked to evaluate a situation they were not actually a part of. It may be that the safety ratings would have been different if the subjects had been asked to put themselves in the shoes of the pedestrians or to go through a real interaction experience themselves. However, observed interactions are more common than personal encounters. Thus, collecting safety assessments indirectly is a commonly used procedure [43]. Further, particularly in pandemic times, the visual presentation helped reach many participants. Especially because the autonomous cargo bike is still under development. Secondly, since the current work used a within-subject design, it was not possible to directly examine the interrelationship between perceived safety and the general acceptability of the cargo bike. Although it is generally accepted that perceived safety is one of the key predictors of acceptability [1], [5], [20], future studies using a between-subject design could provide further insights. In addition, it is advisable to increase the number of participants in the study to enhance the validity. Thirdly, due to the development status of the cargo bike, it was unfortunately not possible to vary the parameters in scenario 3 (i.e., approach speed and deceleration rate) further. However, subsequent studies should imperatively do so to verify the results. For this purpose, further realistic driving speeds, as well as deceleration, should be diversified. The results for scenario 3 are therefore not necessarily generalizable and should be interpreted with reservations. However, the present study also aimed to demonstrate the importance of considering safety perception already during development. The distances determined in scenario 3 can therefore primarily serve as reference distances for subsequent studies.

VII. CONCLUSION

Three main implications for practice or implementation can be derived from our study. First, it addresses the acceptability discourse of new, disruptive technologies such as autonomous driving. In Germany, where our study took place, there is general talk of skepticism towards this technological innovation, but our study results (see also [12]) show that an autonomous micro-mobile such as the autonomous cargo bike does have high acceptability and is assessed as a safe means of transportation. Such results should encourage practitioners, but also funding agencies, to tackle further tests in real settings or first implementation trials.

Second, our study showed possibilities of trial methods that are well usable in times of pandemics and limited contact opportunities. Although the situations we showed via video only provided a second-hand experience and certainly lagged behind, e.g., virtual reality simulations in terms of immersion, valid results could be found. A limiting factor is that we recruited a possibly selected and non-representative sample. However, the mixed-method approach of mediating from real situations via video and using an online questionnaire enabled us to reach a larger sample than usual in real tests or focus groups, thus being able to draw conclusions across a larger number of people.

Third, the present results can be used as reference variables for future studies to approach the objectification of subjective phenomena (i.e., perceived safety) and to integrate findings into motion planning algorithms. This would allow a motion planning algorithm to appropriately consider the perceived danger of road users, as opposed to ensuring safety in an objective collision avoidance manner. We argue for the need in research to investigate parameters, such as speed and distance, that can be used to anticipate a human response in the design and implementation of autonomous mobility technologies - specifically the perception of safety of vulnerable groups in shared spaces.

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The experiments conducted for the present thesis research apply to the ethical principles stated by the American Psychological Association for psychological research with human participants. Before the experiment all individuals were informed about the basic intent of the study and gave their consent to participate.

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