Survey on eHMI concepts: The effect of text, color, and perspective

Pavlo Bazilinskyy[1], Dimitra Dodou[2], Joost de Winter[1]
1. Department of Cognitive Robotics, Faculty of Mechanical, Maritime and Materials Engineering, Delft University of Technology, Delft, The Netherlands, p.bazilinskyy@tudelft.nl, j.c.f.dewinter@tudelft.nl
2. Department of Biomechanical Engineering, Faculty of Mechanical, Maritime and Materials Engineering, Delft University of Technology, Delft, The Netherlands, d.dodou@tudelft.nl

Abstract
The automotive industry has presented a variety of external human-machine interfaces (eHMIs) for automated vehicles (AVs). However, there appears to be no consensus on which types of eHMIs are clear to vulnerable road users. Here, we present the results of two large crowdsourcing surveys on this topic. In the first survey, we asked respondents about the clarity of 28 images, videos, and patent drawings of eHMI concepts presented by the automotive industry. Results showed that textual eHMIs were generally regarded as the clearest. Among the non-textual eHMIs, a projected zebra crossing was regarded as clear, whereas light-based eHMIs were seen as relatively unclear. A considerable proportion of the respondents mistook non-textual eHMIs for a sensor. In the second survey, we examined the effect of perspective of the textual message (egocentric from the pedestrian's point of view: 'Walk', 'Don't walk' vs. allocentric: 'Will stop', 'Won't stop') and color (green, red, white) on whether respondents felt safe to cross in front of the AV. The results showed that textual eHMIs were more persuasive than color-only eHMIs, which is in line with the results from the first survey. The eHMI that received the highest percentage of 'Yes' responses was the message 'Walk' in green font, which points towards an egocentric perspective taken by the pedestrian. We conclude that textual egocentric eHMIs are regarded as clearest, which poses a dilemma because textual instructions are associated with practical issues of liability, legibility, and technical feasibility.

Keywords
Automated vehicles; Crowdsourcing; Online surveys; External Human-Machine Interface (eHMI)

1. Introduction

Cars are increasingly computerized. Advanced driver assistance systems such as forward collision warning systems, adaptive cruise control, and lane departure warning systems are now installed not only in luxury models but also in low- and mid-range vehicles. In the future, highly automated vehicles (AVs), in which the driver does not have to monitor the environment, might be driving on public roads. The development of fully automated driving is picking up pace as well: Waymo drove over 5 million miles autonomously in 2018 alone (Waymo, 2019).

Today, human drivers employ various gestures (e.g., hand gestures, eye contact, high beam lighting) to communicate with other road users, especially in situations where no formal rules apply (Färber, 2016; Šucha, 2014). The role of the driver in an AV will differ from that of a manual driver. In particular, the human inside the car may be engaged in a non-driving task and unavailable to interact with other road users (Lundgren et al., 2017) or take part in negotiations (Färber, 2016).

Although implicit communication in the form of relative distance and speed of the AV is useful for other drivers (Oliveira, Proctor, Burns, & Birrell, 2019) and to pedestrians in deciding whether to cross the road (e.g., Ackermann, Beggiato, Bluhm, Löw, & Krems, 2019; AlAdawy et al., 2019; Clamann, Aubert, & Cummings, 2017; Dey & Terken, 2017; Schmidt, Terwilliger, AlAdawy, & Fridman, 2019), it has been argued that AVs may need to employ explicit communication in addition. Explicit communication can be provided using a so-called external human-machine interface (eHMI) to compensate for the lack of communication by the human in the car (Lundgren et al., 2017; Schieben et al., 2019). Industry and academia have suggested a large variety of designs for eHMIs, but there appears to be no consensus on which type of eHMI should be used. Herein, we examine the topics of text, color, anthropomorphism, and perspective, on the clarity of eHMIs for vulnerable road users.

1.1 Textual versus non-textual messages

Icons are commonly used in traffic signs. It has been argued that icons are advantageous compared to text, as the former can overcome natural language barriers (Krampen, 1965, 1983). Also, icon-based traffic signs are considered more conspicuous, legible from a greater distance, and better understood than textual traffic signs (Ells & Dewar, 1979; Jacobs, Johnston, & Cole, 1976; Kline, Ghali, Kline, & Brown, 1990). Others have reported that the effectiveness of icons depends on prior exposure and that, for first-time users, the interpretation of icons takes longer and is more error-prone than textual information (Goonetilleke, Martins Shih, On, & Fritsch, 2001; Huang & Bias, 2012). The effectiveness of an icon further depends on its concreteness, semantic distance, and familiarity (McDougall, Curry, & De Bruijn, 1999), as well as its representational strategy, that is, whether the icon depicts a literal representation (e.g., a gas pump), an abstract representation (e.g., a knife and a fork to indicate a restaurant), or an arbitrary representation (e.g., a red cross for first aid) (Lodding, 1983; and see Lidwell, Holden, & Butler, 2003; Purchase, 1998; Rogers, 1989; and Webb, Sorenson, & Lyons, 1989, for similar icon taxonomies). Adding a textual explanation to an icon can help to understand the meaning of the icon (Davies, Haines, Norris, & Wilson, 1998; Huang & Bai, 2014; Shinar & Vogelzang, 2013) but may also lead to confusion and delayed responses (Viganò & Rovida, 2015).

It is presently unknown whether eHMIs should use icons (e.g., Walk/Don't walk pedestrian sign: Deb, Strawderman, & Carruth, 2019; De Clercq, Dietrich, Núñez Velasco, De Winter, & Happee, 2019; Fridman et al., 2019; red upraised hand: Deb, Hudson, Carruth, & Frey, 2018; zebra crossing projected on the road: Dietrich, Willrodt, Wagner, & Bengler, 2018; footprints projected on the road: Deb et al., 2019), whether text should be used instead (e.g., 'Walk': Deb, Warner, Poudel, & Bhandari, 2016; Hudson, Deb, Carruth, McGinley, & Frey, 2019; 'Walk'/'Don't Walk': Fridman et al., 2019; 'Go': Vlakveld & Kint, 2019; 'Cross now': Matthews, Chowdhary, & Kieson, 2017; 'After you': Nissan, 2015; 'Braking': Deb et al., 2016), or whether a combination of icons and text is preferred. According to Löcken, Wintersberger, Frison, and Riener (2019), pedestrians would benefit from types of communication derived from established concepts like traffic signs or traffic indicators.

1.2 Anthropomorphic versus non-anthropomorphic gestures

In natural conversations, humans rely on nonverbal communication such as facial expressions, eye contact, head movements, and hand gestures (Cassell, Sullivan, Churchill, & Prevost, 2000; Ekman & Friesen, 1969; Knapp, 1980; Mehrabian, 1972). Early research on computer-mediated communication has argued that a lack of nonverbal cues might lead to difficulties in interpreting the meaning and significance of the message from the computer (Kiesler, Siegel, & McGuire, 1984).

Robots are often anthropomorphized by incorporating a human-like physical shape and human-like behavior, including eye contact, facial expression, and posture (Cassell et al., 2000; Cowell & Stanney, 2005; Reeves & Nass, 1996). It has been argued that anthropomorphism promotes likeability, trust, and willingness to respond to the actions of the virtual or robotic agent (Carter, Mistry, Carr, Kelly, & Hodgins, 2014; De Visser et al., 2016; Epley, Waytz, & Cacioppo, 2007; Salem, Eyssel, Rohlfing, Kopp, & Joublin, 2011). In automated driving research, Lee, Kim, Lee, and Shin (2015) and Waytz, Heafner, and Epley (2014) found that driving agents with anthropomorphic features were regarded as more trustworthy than non-communicating/non-anthropomorphic ones. However, it is unclear whether anthropomorphic cues assist in message conveying, decision-making, and communication. For example, in a study that investigated several ways (e.g., sound, gazing, waving, eye contact) of attracting the attention of older persons, eye contact was found to be the least salient and associated with the slowest response times (Torta, Van Heumen, Cuijpers, & Juola, 2012). Similarly, in Fiore et al. (2013), the robot's implicit communication (passive vs. active behavior when crossing paths with a human), not the gaze of its mechanical eyes, was found to offer significant cues regarding the robot's social presence. Burgoon et al. (2000) compared face-to-face communication with anthropomorphic (animated face, voice) and non-anthropomorphic (text-only) human-computer interfaces and found that, while face-to-face communication and anthropomorphic interfaces were deemed more sociable and credible, text-only interfaces had the strongest influence on decision-making.

Several anthropomorphic eHMIs for AVs have been proposed, including eyes (Chang, Toda, Sakamoto, & Igarashi, 2017; Pennycooke, 2012), a smile (De Clercq et al., 2019; Deb, Strawderman, & Carruth, 2018), and a facial shape (Mahadevan, Somanath, & Sharlin, 2018; Mirnig, Perterer, Stollnberger, & Tscheligi, 2017). Others have opted for non-anthropomorphic eHMIs, such as lamps or light bars. For example, Benderius, Berger, and Lundgren (2018) proposed a light bar of which the width, flashing, and color could change to warn other road users or indicate the intended movement of the AV. Light bars that indicate the status of the AV were also proposed by Cefkin, Zhang, Stayton, and Vinkhuyzen (2019) and Hensch, Neumann, Beggiato, Halama, and Krems (2019). Böckle, Brenden, Klingegård, Habibovic, and Bout (2017) assessed pedestrians' perception of safety and comfort for an eHMI consisting of four light columns that changed color and flashing to indicate whether the AV was stopping, not stopping, waiting, or starting to drive. A light strip that contracted to indicate that the AV started moving and expanded to indicate yielding was tested by Lagstrom and Lundgren (2015). The authors found that the concept required a short period of training (see also Habibovic et al., 2018a, 2018b). Finally, De Clercq et al. (2019) tested a light moving from left to right to indicate that it is safe to cross. Whether anthropomorphic gestures lead to safer and more efficient communication with human road users than non-anthropomorphic gestures is unknown.

1.3 Perspective-taking

Perspective-taking is an integral part of communication. It has been argued that people initially anchor to their own perspective and that adjusting towards a different perspective requires time and effort (Keysar, 2007). People's adherence to an egocentric perspective increases with time pressure and decreases when there are incentives for accuracy (Epley, Keysar, Van Boven, & Gilovich, 2004). Egocentric errors in language use have also been reported, where a failure of adjustment of perspective may lead to miscommunication (Keysar & Barr, 2002; Keysar, Barr, & Horton, 1998).

Messages of eHMIs can be divided into two categories: messages that refer to the pedestrian (egocentric perspective from the pedestrian's viewpoint; e.g., 'Walk': Deb et al., 2016; Hudson et al., 2019; 'Go': Vlakveld & Kint, 2019; 'Cross now': Matthews et al., 2017) and messages that refer to the AV (allocentric perspective; e.g., 'Braking': Deb et al., 2016; 'Stopping': Nissan, 2015). A further distinction can be made between allocentric messages regarding the current state of the AV (e.g., 'Braking') and the target state of the AV (e.g., 'Stopping'). It is currently unclear whether AVs should indicate their state or the action required from the pedestrian. For example, Ackermann, Beggiato, Schubert, and Krems (2019) argued that "direct instructions to cross the street are preferred over status information of the vehicle" (p. 272), whereas Volvo recommended that "it is … important that we do not instruct others what to do next, to avoid potential confusion" (Volvo Cars, 2018a), and Cefkin (2018) similarly argued that an eHMI should "communicate its own state; not instruct others".

1.4 Text-color congruence

An important design consideration for any eHMI is color. In the well-established Stroop task paradigm (Stroop, 1935), it takes longer to identify the ink color of a word when the ink color is incongruent with the word (e.g., if the word 'red' is printed in blue). Dalrymple-Alford (1972) (and earlier Klein, 1964 for incongruent stimuli only) showed that a Stroop interference does not only occur with color words but also with color-related words (e.g., sky, grass, snow, blood).

It has long been documented that, in traffic signals, red requires the operator to stop, whereas green indicates freedom to proceed (Mulligan, 1936). Stroop-like interference has been reported for pedestrian traffic signs, with a congruent color and posture of the traffic sign (i.e., a green walking figure and a red standing figure) yielding higher accuracy and faster responses than incongruent combinations (i.e., a red walking figure and a green standing figure; Kandil, Olk, & Hilgetag, 2017).

For new types of eHMI, the meaning of color could be confusing. While traffic signs are static elements of the road infrastructure, an AV is moving, which creates ambiguity about whether the eHMI message refers to the AV itself or other road users. In Zhang, Vinkhuyzen, and Cefkin (2017), a light strip on the front door and hood was static and green to indicate that the AV was waiting and red and rapidly moving to indicate that the AV was moving (i.e., an egocentric perspective for the pedestrian in terms of color). However, participants associated the static green light with a moving vehicle and the red moving light with a stopping vehicle (i.e., an allocentric perspective in terms of color), opposite to the authors' intended design. In Fridman et al.'s (2019) survey study, green or red headlamps/strips were deemed ambiguous by the majority of the respondents.

1.5 *Survey Study 1: Evaluating eHMI concepts from industry*

This study consists of two large crowdsourcing surveys. The first survey was concerned with eHMI concepts that are now distributed in the media. Automotive companies build concept cars and present them at car shows and the media for multiple purposes, including the acceleration of new technological developments, to provide a statement of intent or vision, to infer the market potential of a new concept by polling the reaction of press and public, to gain media attention, to improve the image of the brand, or to showcase new technology (Caldwell, 2019; Leggett, 2018; Redding, 2017).

There are various reasons why it is important to assess the eHMI concepts that have been proposed by the industry:

- eHMIs from industry likely have a large impact on public opinion. Research papers receive a relatively limited number of views (primarily by peer researchers), whereas some automotive industry concepts receive thousands or even millions of views. For example, the video 'The ideas behind the BMW VISION NEXT 100' has been viewed 1,981,596 times, as of August 16, 2019 (BMW, 2016).
- The industry has the final authority because it is the industry that will eventually bring eHMIs onto the market. Although concept cars themselves are not intended for production, they may express the company's vision of how eHMI technology will be embodied in future cars.

- Various eHMI concepts designed by academics have already been evaluated, as cited above. However, so far, a formal evaluation of eHMI concepts from industry is lacking, making it pertinent to perform such an evaluation. It is impossible to compare eHMIs from industry in a controlled manner, as manufacturers all present their eHMIs in different modes. However, it may still be worthwhile to compare these concepts on factors such as clarity, with the mode of presentation as a moderating variable.

An inherent disadvantage of Survey 1 is that the diverse presentation modes of the eHMI concepts on the internet (images, videos, animations, different scenarios and environments, etc.) do not allow for a controlled comparison. It may be possible to counteract this problem by pre-selecting the material, making screenshots of the videos, and cropping the images, to obtain comparable traffic scenarios and viewing angles. However, this would be a subjective process, and some differences in vehicle behavior and scenarios would remain. Instead of manipulating the available material, we chose to present the eHMI concepts to the participants in the original media format as retrieved from the internet. Our assumption is that the industry posts material on the internet in a manner that is favorable to them, and which is meant for public viewing.

1.6 *Survey Study 2: Controlled comparison of text, perspective, and color*

Because Survey 1 lacks experimental control, we conducted a second survey based on the findings of the first survey. In this second survey, we investigated, in a controlled manner, the clarity of eHMIs as a function of (1) the presence or absence of text, (2) the perspective of the conveyed message, and (3) color.

We assessed the respondent's initial reaction to the eHMIs, as we did not develop or offer eHMI-specific training. De Clercq et al. (2019) found that participants learned to understand a new eHMI that does not feature stimulus-response compatibility (e.g., an ambiguous led strip movement) after only a few trials of exposure. However, the problem is that multiple eHMIs are currently being proposed by the industry. If different eHMIs are brought onto the market, they will need to be understood intuitively. Yet, even if only one standardized eHMI design were available in future traffic, it would still be important that this eHMI is understood without training. It is known that, especially in cases of stress, humans tend to fall back on their initial habits rather than their learned behavior (Taylor & Garvey, 1959).

2. Survey 1

2.1 Methods of Survey 1

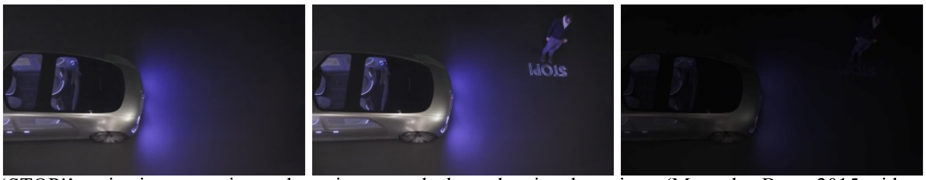
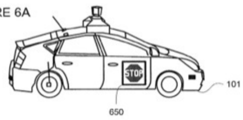
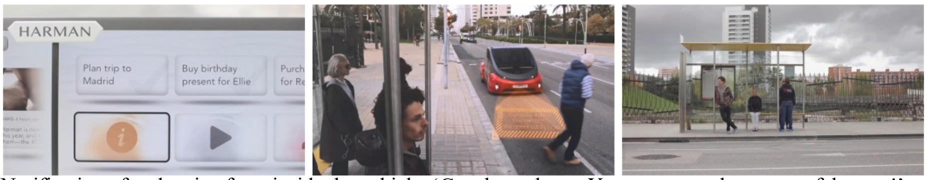
We conducted internet and patent searches in 2017 up till September 2018 to retrieve visual eHMI concepts provided by the industry. The selection criteria were: 1) the eHMI concept had to be from a company, not from an academic research group, and 2) the concept had to be visualized through a drawing, image, or video. We retrieved 28 images, videos, and patent drawings illustrating 22 different eHMI concepts, see Table 1. Some companies presented more than one concept, and some concepts were represented by more than one image, video, or drawing; we included all retrieved representations, which explains why the number of representations is larger than the number of eHMI concepts and companies.

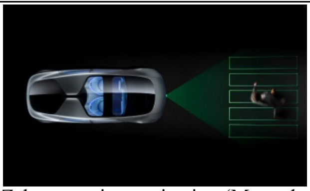
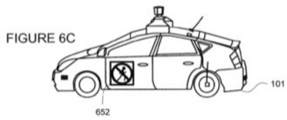
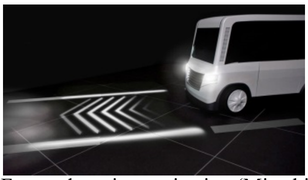
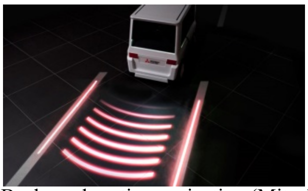
The 22 eHMI concepts can be categorized into various types: (1) 1 concept was based on anthropomorphic gestures (smile), 2 on anthropomorphic as well as non-anthropomorphic gestures (e.g., eyes and lights), and 19 on non-anthropomorphic gestures (e.g., lights); (2) 4 concepts were textual (e.g., 'go ahead'), 11 non-textual (i.e., icons and symbols such as arrows, zebra crossings, light bars, etc.), and 7 included both text and icons/symbols; (3) 11 concepts presented messages from an egocentric perspective for the pedestrian (e.g., 'STOP'), 6 from an allocentric perspective (e.g., 'stopping'), 4 from both perspectives (e.g., 'Car slows down. You can cross the street safely now!'), and 1 had a message with unknown perspective.

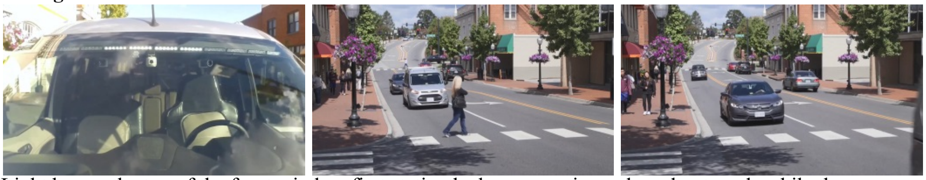
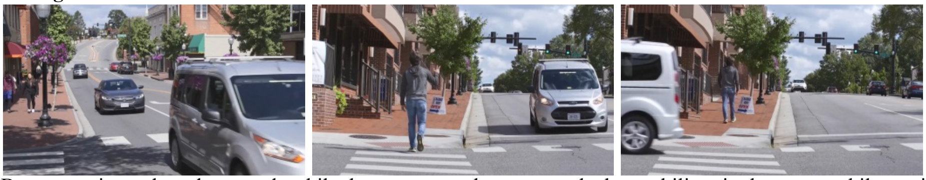
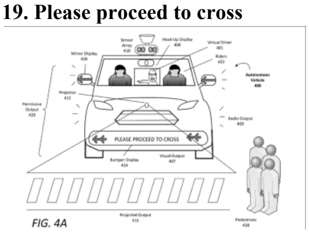
One may notice from Table 1 that six of the concepts used a shade of cyan/turquoise. It has been argued that cyan/turquoise is a promising color choice for automated cars because it has good visibility, is perceivable by color-deficient individuals, and is not yet used in traffic signs (Dietrich et al., 2018; Werner, 2018).

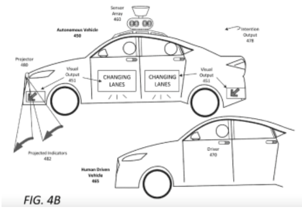
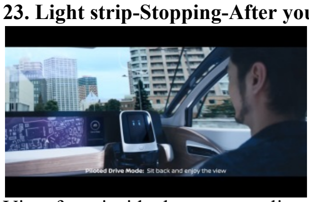
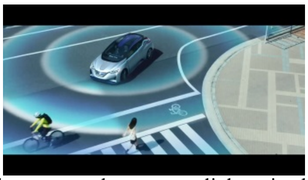
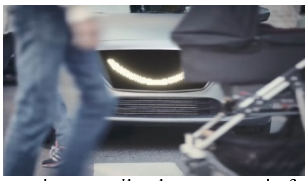
Table 1. eHMIs for AVs proposed by the industry.

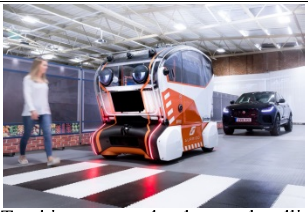
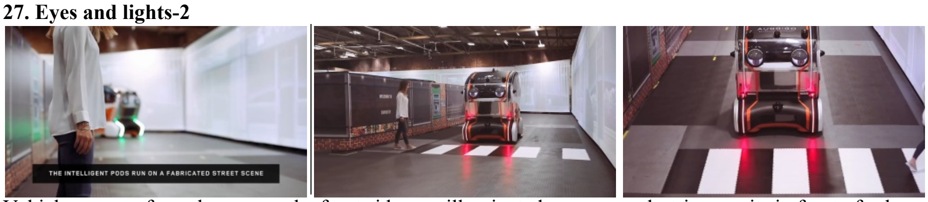
eHMI	**Characteristics** • Anthropomorphic/Non-anthropomorphic • Textual/Non-textual • Egocentric/Allocentric • Color

	• Representation
1. After you  'After You' on the windshield (Nissan, 2015)	• Non-anthropomorphic • Textual • Ego+Allocentric • Cyan • Image
2. STOP-1  'STOP!' projection appearing and moving towards the pedestrian three times (Mercedes-Benz, 2015; video taken from AutoMotoTV, 2015a)	• Non-anthropomorphic • Textual • Egocentric • Violet • Video (11.31 s)
3. STOP-2 FIGURE 6A  'STOP' sign on the car door (Google/Waymo; Urmson, Mahon, Dolgov, & Zhu, 2015)	• Non-anthropomorphic • Textual • Egocentric • No color • Patent
4. Car slows down  Notification of pedestrian from inside the vehicle; 'Car slows down. You can cross the street safely now!' projection while pedestrian crosses (Rinspeed AG, 2017)	• Non-anthropomorphic • Textual • Ego+Allocentric • Brown/orange • Video (6.81 s)
5. Light strip-1  Rhomb-shaped light and moving strip (from the pedestrian side towards the other side of the road) on the windshield (BMW, 2016; video taken from Car TV, 2016)	• Non-anthropomorphic • Non-textual • Egocentric • Light changes between white and green • Video (8.38 s)
6. Zebra-1  Zebra crossing projection (Mercedes-Benz, 2015)	• Non-anthropomorphic • Non-textual • Egocentric • Turquoise • Image
7. Zebra-2	• Non-anthropomorphic • Non-textual • Egocentric

 Zebra crossing projection (Mercedes-Benz, 2015)	• Green • Image
8. Zebra-3  Projection of curved lines while the car approaches the pedestrian; the bumper light strip grows upwards, splits and moves outwards, a zebra crossing is projected, the bumper light strip and zebra crossing move/roll from the pedestrian side towards the middle of the road, and the projection disappears after pedestrian has crossed the road (Mercedes-Benz USA, 2015; video taken from AutoMotoTV, 2015b)	• Non-anthropomorphic • Non-textual • Egocentric • Curved lines: white; zebra crossing: white first, then green • Video (20.60 s)
9. Do not walk symbol  Do-not-walk sign on the car door (Google/Waymo; Urmson et al., 2015)	• Non-anthropomorphic • Non-textual • Egocentric • No color • Patent drawing
10. Door opening  Door opening projection (Mitsubishi Electric, 2015)	• Non-anthropomorphic • Non-textual • Allocentric • Turquoise • Image
11. Forward motion  Forward motion projection (Mitsubishi Electric, 2015)	• Non-anthropomorphic • Non-textual • Allocentric • White • Image
12. Backward motion  Backward motion projection (Mitsubishi Electric, 2015)	• Non-anthropomorphic • Non-textual • Allocentric • Red • Image
13. Light strip-2  Light strip on the car windshield and side (Volvo Cars, 2018b)	• Non-anthropomorphic • Non-textual • Allocentric • First light cyan, then yellow

	• Video (8.52 s)
14. Light bar-1  Light bar on the top of the front window first static; the bar moves inwards and outwards while the car approaches and stops in front of a zebra crossing; a pedestrian crosses, after which the bar centralizes, flashes four times, and becomes static when the car starts moving again (Ford Media Center, 2017)	• Non-anthropomorphic • Non-textual • Unknown perspective • White • Video (18.03 s)
15. Light bar-2  Bar moves inwards and outwards while the car approaches corner; the bar stabilizes in the center while turning indicator turns on, and a pedestrian crosses zebra intersection; the car turns into the corner (Ford Media Center, 2017)	• Non-anthropomorphic • Non-textual • Unknown perspective • White • Video (9.70 s)
16. Light bar-3  A cyclist is seen from inside the car; the car stops at zebra crossing; the light bar moves outwards and inwards while the cyclist crosses the road, after which bar centralizes, flashes four times, and becomes static when the car starts moving again (Ford Media Center, 2017)	• Non-anthropomorphic • Non-textual • Unknown perspective • White • Video (11.91 s)
17. Go ahead  'go ahead' and '>' sign on bumper (Daimler, 2017)	• Non-anthropomorphic • Textual + Non-textual • Egocentric • Turquoise • Image
18. Safe to cross  'Safe to Cross' and pedestrian on zebra crossing on car top (drive.ai, 2018; image taken from Golson, 2016)	• Non-anthropomorphic • Textual + Non-textual • Egocentric • Black letters on light blue background • Image
19. Please proceed to cross  'PLEASE PROCEED TO CROSS' and arrows on the bumper, head-up display of virtual driver, zebra crossing projection (Uber Technologies, Inc; Sweeney, Pilarski, Ross, & Liu, 2018)	• Non-anthropomorphic • Textual + Non-textual • Egocentric • No color • Patent drawing
20. Turning left	• Non-anthropomorphic • Textual + Non-textual • Allocentric

 ‘TURNING LEFT’ and left arrow on bumper (Toyota, 2018)	• Light pink • Image
21. Changing lanes  ‘CHANGING LANES’ and arrows on the car side (Uber Technologies, Inc; Sweeney et al., 2018)	• Non-anthropomorphic • Textual + Non-textual • Allocentric • No color • Patent drawing
22. Waiting for you to cross  ‘Waiting for You to Cross’ and pedestrian on zebra crossing on car side (drive.ai, 2018)	• Non-anthropomorphic • Textual + Non-textual • Ego+Allocentric • Green letters, white icon, on black background • Image
23. Light strip-Stopping-After you    View from inside the car; a cyclist appears next to the car; a white light bar moves along a cyan light strip above car doors; ‘Stopping’ message on the windshield; ‘After You’ message on the windshield (Nissan, 2015)	• Non-anthropomorphic • Textual + Non-textual • Ego+Allocentric • White/cyan • Video (9.85 s)
24. Smile-1  Smile-shaped light bar on the bumper (Semcon, 2016; image taken from Peters, 2016)	• Anthropomorphic • Non-textual • Egocentric • White/light yellow • Image
25. Smile-2    Horizontal light bar on the bumper turns into a smile; the car stops in front of a zebra crossing, several pedestrians cross in both directions (Semcon, 2016; video taken from Peters, 2016)	• Anthropomorphic • Non-textual • Egocentric • White/light yellow • Video (7.24 s)
26. Eyes and lights-1	• Anthropomorphic +

 Tracking eyes and red-green headlights (Jaguar Land Rover, 2018)	Non-anthropomorphic • Non-textual • Color: allocentric; Eyes: egocentric • Red/green • Image
27. Eyes and lights-2  Vehicle appears from the corner, the front sides are illuminated green; a pedestrian awaits in front of zebra crossing; animated eyes look at the pedestrian, then at the zebra crossing back and forth while the front side lights turn red; the vehicle stops in front of zebra crossing; the pedestrian crosses (Jaguar Land Rover, 2018)	• Anthropomorphic + Non-anthropomorphic • Non-textual • Color: allocentric; Eyes: egocentric • Red/green • Video (11.84 s)
28. Go ahead and eyes  Car moves on road; '11th street' on the bumper, the car stops in front of zebra crossing; 'go ahead' and '>' sign appears on the bumper, and headlights turn into animated eyes; the pedestrian crosses (Daimler, 2017)	• Anthropomorphic + Non-anthropomorphic • Textual + Non-textual • Egocentric • Turquoise • Video (7.55 s)

A survey with images and videos of the eHMIs was created using the crowdsourcing service Figure-Eight (www.figure-eight.com). We allowed respondents from all countries to participate in our survey. Respondents could become aware of the survey via so-called channel websites such as clixsense.com. The demographic composition of crowdworkers at Figure-Eight is diverse and varies over time. At the moment of completing the survey, the crowdsourcing service was especially popular in Venezuela, the USA, India, and Egypt. Recent literature provides a possible explanation for the high number of respondents from Venezuela: "a major economic crisis in Venezuela caused many people to sign up to our platform in order to earn money in a more stable currency, biasing the available workforce when most contributors are from the same country, culture, and speak the same language" (Barbosa & Chen, 2019).

At the beginning of the survey, the contact information of the researchers was provided, and the purpose of the survey was described as '*to explore the public opinion on the use of visual and auditory interfaces for interaction between automated vehicles and pedestrians or cyclists*'. Contributors from all countries were allowed to participate in the survey, to collect data from an as large and diverse population as possible. Completing the survey more than once from the same worker ID was not allowed. A payment of $0.25 was offered for completing the survey.

The drawings, images, and video items were embedded in the survey. For the concepts represented by drawings and images, only one drawing or image was shown per concept. For each eHMI, respondents answered to the statement '*The instructions of the car in concept N above are clear to me*' on a 5-point Likert scale from (1) '*disagree strongly*' to (5) '*agree strongly*', together with a sixth option '*I prefer not to respond*'. Additionally, respondents were asked '*What message does the car show in concept X above?*', for which a textual response was needed. In both cases, *X* indicates the number of the concept, as it appeared to the respondent. The order of the items was randomized.

2.2 Results of Survey 1

A total of 1770 respondents participated between 3 and 29 October 2018. The respondents resided in 74 countries, with the most represented countries being Venezuela (*N* = 789), USA (*N* = 107), India (*N* = 95), and Egypt (*N* = 58). The survey received a satisfaction rating of 3.9 on a scale from 1 ('*very dissatisfied*') to 5 ('*very satisfied*'). The respondents took on average 17.8 min to complete the survey (*SD* = 7.2 min).

Respondents who indicated that they had not read the instructions ($N = 23$) and respondents who indicated that they were under 18 ($N = 3$) were excluded. Additionally, respondents who provided only a brief (< 4 characters) textual input or used a non-ASCII character in the free-response item for more than 3 of the 28 images, videos, and patent drawings were excluded ($N = 203$). Finally, we excluded 115 respondents who selected the '*I prefer not to respond*' response option in more than three of the multiple-choice questions. In total, 304 surveys were removed, leaving 1,466 respondents from 72 countries. The sample consisted of 923 males and 540 females (3 respondents reported '*I prefer not to respond*' to the gender question). The mean age of the respondents was 34.3 years ($SD = 11.3$). From the 1,466 respondents, the four most highly represented countries were Venezuela, USA, India, and Egypt, with 620, 93, 86, and 50 respondents, respectively.

Figure 1 shows the mean clarity ratings of the 28 images, videos, and patent drawings, with the color of the bars indicating whether the eHMI was textual (orange) or non-textual (gray). Overall, eHMIs containing text were regarded as clearer than non-textual eHMIs. Among the latter, the zebra crossing was the clearest, and light-based eHMI were perceived as less clear. There were no consistent differences in clarity ratings between ego- and allocentric eHMIs. However, the four clearest eHMIs contained text with an egocentric reference ('go ahead', 'Safe to Cross') or a combination of ego- and allocentric perspectives ('Waiting for You to Cross'). The best-ranked eHMI was a video demonstrating a combination of text ('Go ahead') and anthropomorphic features (eyes). The videos of the two other eHMIs that included anthropomorphic features were ranked 12th (eyes and lights) and 14th (smile), and the corresponding images were ranked 19th and 20th. Of the top ten eHMIs in terms of clarity, six were images, and four were videos. The colors of the eHMIs were too variable to allow for a meaningful interpretation of their clarity.

Because of the substantial sample size, most differences between the clarity ratings of pairs of responses were statistically significant. For example, even for the small difference between the mean clarity rating for the 'Go ahead' ($M = 4.43$, $SD = 0.90$) and Zebra-3 ($M = 4.33$, $SD = 1.00$) eHMIs, a paired t-test showed a significant effect, $t(1457) = 3.60$, $p = 0.00033$. Because even small effects were statistically significant, we refrained from reporting p-values.

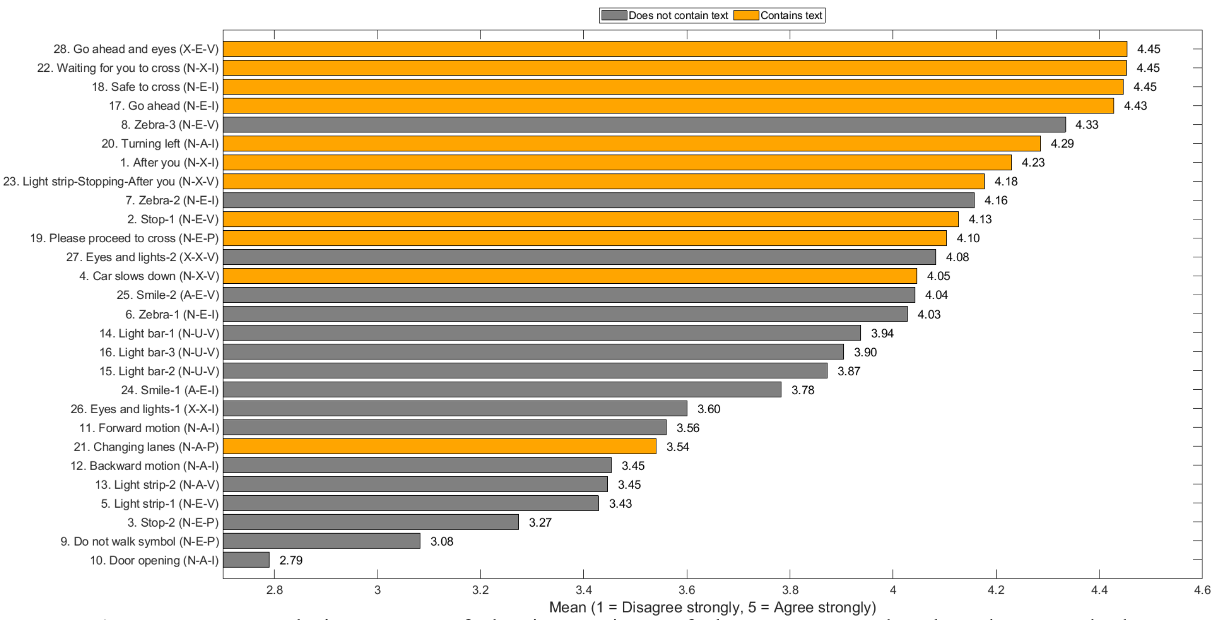


Figure 1. Mean eHMI clarity scores of the instructions of the concepts. The three-letter code between parentheses indicates whether the eHMI was (1) anthropomorphic (A) or non-anthropomorphic (N), (2) egocentric (E), allocentric (A), and represented by (3) an image (I), a video (V), or a patent drawing (P). X indicates unknown (in the case of Light bar 1–3) or a combination of both options (i.e., anthropomorphic & non-anthropomorphic; egocentric & allocentric).

We analyzed the prevalence of words in the 41,048 textual responses (1,466 respondents x 28 images, videos, and patent drawings) to the question '*What message does the car show in concept X above?*'. The most frequently used words were 'cross' (mentioned in 9,632 responses), 'car' (6,453), and 'pedestrian' (6,012). Of interest is that some respondents thought that the concept is a 'sensor' or something that is 'scanning' the environment (these words were mentioned in 1,591 and 66 responses, respectively). The results in Figure 2 indicate that attributing sensor or scanning capabilities to an eHMI primarily concerned the non-textual eHMIs.

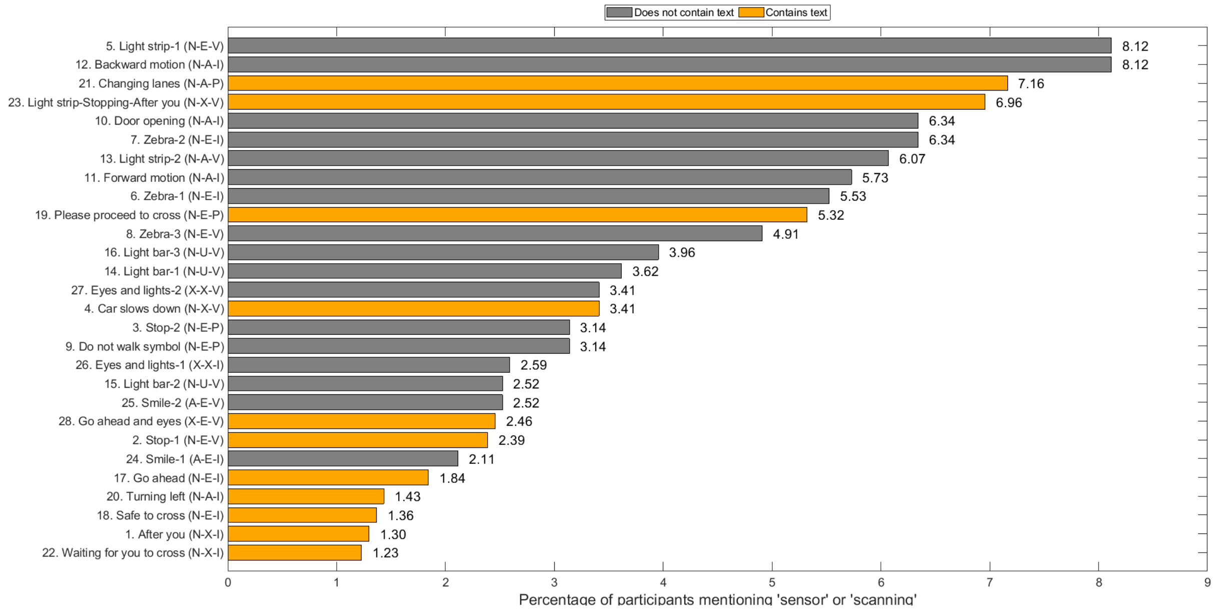


Figure 2. Percentage of respondents who reported 'sensor' or 'scanning' when describing the concepts. Abbreviations are the same as in Figure 1.

Figure 3 shows the correlation between clarity rating and whether respondents were from English-speaking countries. Respondents from English-speaking countries found textual eHMIs clearer than respondents from countries in which English is not an official language.

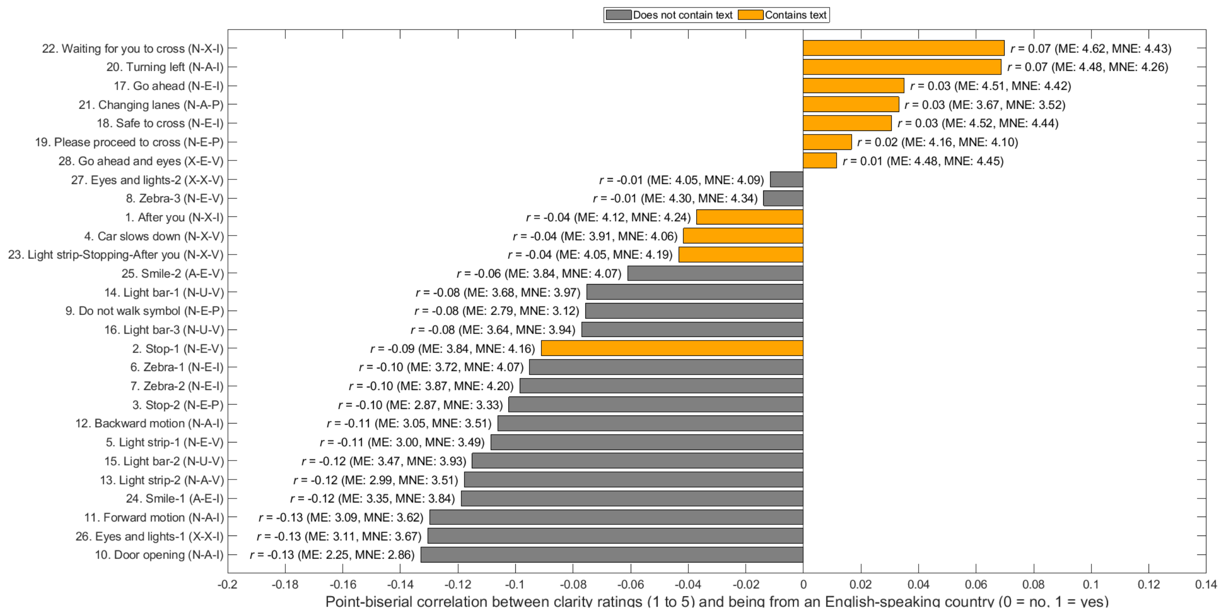


Figure 3. Point-biserial correlation (*r*) between the respondents' clarity rating per eHMI and whether respondents were from an English-speaking country (1) or not (0). Abbreviations are the same as in Figure 1. ME = mean clarity rating (1 = Disagree strongly, 5 = Agree strongly) of respondents from English-speaking countries. MNE = mean clarity rating of respondents from non-English speaking countries.

3. Survey 2

3.1 Methods of Survey 2

Because textual eHMIs received the highest clarity ratings in Survey 1, Survey 2 focused on this type of eHMIs. In Survey 2, we also varied the text content and color. Again, we allowed respondents from all countries to participate. Even though respondents from English-speaking countries gave higher clarity ratings to textual eHMIs as compared to respondents from non-English speaking countries, textual eHMIs were scored as the clearest by English native as well as nonnative speakers (Fig. 3).

We presented respondents with 15 concepts of eHMIs (see Fig. 4): four textual messages ('WALK', 'DON'T WALK', 'WILL STOP', and 'WON'T STOP') and an empty display, all in each of three colors (green, red, and white). We opted for green and red because these colors are already used in traffic signs, which allows us to investigate whether respondents attach the same 'egocentric' meaning to an eHMI (green meaning freedom to cross and red meaning not crossing). The eHMIs were generated with the online tool LCD Display Generator (Avtanski, 2018). The images were of the same size, containing ten blocks on the LCD.

Figure 4. eHMIs used in Survey 2.

The concepts were overlaid on a photo of a test vehicle driving on a road in Delft, The Netherlands (Fig. 5). The concepts were added below the masked number plate. The photo was made during the preparation of an experiment of Rodríguez Palmeiro et al. (2018). We opted for a photo with the driver in the driver's seat because future automated driving systems (at least of SAE levels 3 and 4) will still require that the human is able to take over control.

Figure 5. eHMI concept 'DON'T WALK' in red letters overlaid over the photo. The person in the driver seat provided written consent for the publication of this photo.

At the beginning of Survey 2, the same information regarding the survey aim and duration as in Survey 1 were included. The following instruction was provided: '*You will be presented with a series of images of a vehicle* *approaching a crosswalk. Please try to imagine that you are a pedestrian viewing the approaching vehicle. You will be asked to decide whether it is safe to cross*.' Afterwards, each of the 15 images was depicted.

For each image, respondents answered the question '*Would you feel safe to cross in front of the car above?*' with the options '*Yes*', '*No*', and '*Not sure*' (response options as in Fridman et al., 2019). Then, respondents were asked to reply to the optional question '*If you think that the message on the car above is unclear, please explain why below*' using a text entry. Additionally, respondents were required to answer the question '*What is the color of the text/pixels on the display of the car above?*' with options '*Green*', '*Red*', '*White*', and '*Not sure*'. This test question was added to filter out respondents who answered the questions without paying attention to the question content. The order of the images was randomized per respondent.

Contributors from all countries were allowed to participate in the survey. Completing the survey more than once from the same worker ID was not allowed. A payment of $0.20 was offered for completing the survey

3.2 Results of Survey 2

Two-thousand respondents participated between 25 December 2018 and 4 January 2019. The respondents resided in 78 countries, with the most represented countries being Venezuela (*N* = 835), India (120), USA (*N* = 99), Egypt (*N* = 76), and Ukraine (*N* = 76). The survey received a satisfaction rating of 4.4 on a scale from 1 ('*very dissatisfied*') to 5 ('*very satisfied*').

Respondents who indicated that they had not read the instructions (*N* = 13) or who indicated that they were under 18 (*N* = 2) were excluded. Additionally, 679 respondents who made more than 3 mistakes (out of 15 possible) in specifying the color of the display were removed from the analysis. In total, 681 respondents were removed, leaving 1,319 respondents from 75 countries. The final sample consisted of 833 males and 479 females; 7 respondents did not specify their gender. The mean age of the respondents was 35.8 years (*SD* = 11.4). From the filtered set of 1,319 respondents, the five most highly represented countries were again Venezuela (*N* = 518), India (*N* = 79), USA (*N* = 75), Ukraine (*N* = 51), and Egypt (*N* = 45).

Figure 6 shows the distribution of responses to the question '*What is the color of the text/pixels on the display of the car above?*'. The respondents were relatively uncertain about the color of the empty displays, perhaps because there was no text and it may have been unclear what color they had to report. Furthermore, respondents often interpreted green as white, perhaps because we used a bright green (Fig. 4). Thus, our test questions may have been difficult for the respondents, and some of the wrong answers may have been due to misperception rather than wrong intent. Our threshold of having at least 12 out of 15 test questions correct can be thus regarded as strict.

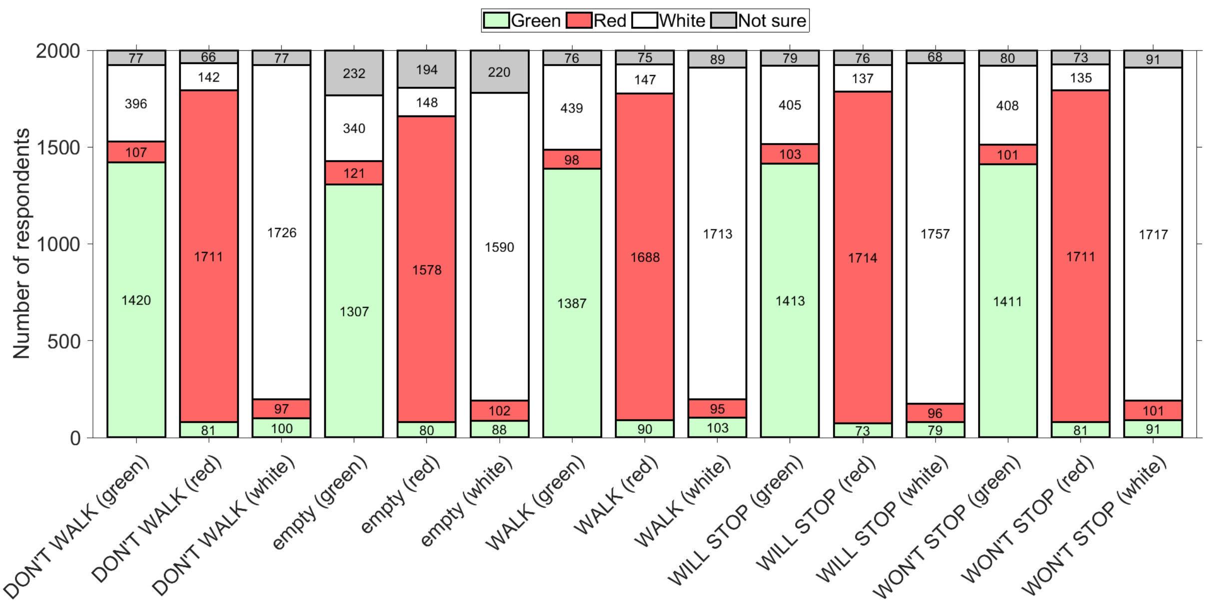


Figure 6. Distribution of answers to the question *'What is the color of the text/pixels on the display of the car above?*' before filtering of data.

Figure 7 shows the percentage of respondents who indicated feeling safe to cross in front of the car for each of the eHMI concepts. The following patterns are observed:

Effects of text content

- The effect of text content was large, with messages that permitted the pedestrian to cross ('WALK' & 'WILL STOP') yielding larger percentages of '*Yes*' responses (56.9–85.6%) than empty displays (14.7–24.7%).
- Text messages that did not permit the pedestrian to cross ('DON'T WALK' & 'WON'T STOP') also had a large effect, as they increased the percentage of '*No*' responses from 47.7–61.9% for the empty display to 73.6–76.1%, and reduced the percentage of '*Not sure*' responses from 23.4–27.6% for the empty display to 5.2–7.4%.
- Respondents regarded the empty displays as ambiguous, as evidenced by a high percentage of '*Not sure*' responses (23.4–27.6%). Table 2 shows examples of comments given by the respondents about why empty displays were unclear. Without text, respondents seemed unsure about the perspective (theirs or the AV's) from which they should interpret the colors.
- There were still a substantial number of respondents not feeling safe to cross while the text suggested that they could (9.2–30.5%) or feeling safe to cross while the text suggested they should not (16.6–20.4%).

Effect of perspective

- Respondents felt safer to cross for the egocentric 'WALK' than for the allocentric 'WILL STOP' (Green: 85.6% vs. 69.5%, Red: 63.8%, vs. 56.9%, White: 80.7% vs. 66.2%). Furthermore, 'WALK' was found to be less ambiguous than 'WILL STOP', as evidenced by the fewer '*Not sure*' (Green: 5.2% vs. 9.8%, Red: 11.1%, vs. 12.7%, White: 7.7% vs. 11.6%) responses for the former.
- Similarly, the percentage of respondents reporting '*Not sure*' indicates that respondents found the egocentric 'DON'T WALK' to be (slightly) less ambiguous than the allocentric 'WON'T STOP' (Green: 6.0% vs. 7.4%, Red: 5.2% vs. 6.4%, White: 6.5% vs. 7.4%).

Effects of color

- For each of the five eHMI types, respondents felt safer to cross when the display was green instead of red. The difference was between 1.7% for the 'DON'T WALK' display (20.4% for green vs. 18.7% for red) and 21.8% for the 'WALK' display (85.6% for green vs. 63.8% for red).
- For the 'WALK', 'WILL STOP', and 'WON'T STOP' displays, a message in white yielded a percentage of '*Yes*' responses between those of '*Yes*' responses for messages in red and green.

Text content and color interaction effects

- The largest effect of color was observed between the green and red 'WALK' ('*Yes*' responses 85.6% and 63.8%, respectively), the green and red 'WILL STOP' ('*Yes*' responses 69.5% and 56.9%, respectively), and the green and red empty displays ('*Yes*' responses 24.7% and 19.6%, respectively). Color had a relatively small effect for the 'DON'T WALK' ('*No*' responses: Green: 73.6%; Red: 76.1%; White: 75.0%) and 'WON'T STOP' ('*No*' responses: Green: 73.5%; Red: 77.0%; White: 73.5%) displays.
- Among the textual displays, the largest effect of color on the ambiguity of the display was observed for the 'WALK' display, for which '*Not sure*' responses increased from 5.2% for green to 11.1% for red, followed by the 'WILL STOP' display, with 9.8% and 12.7% '*Not sure*' responses for the green and red versions, respectively.

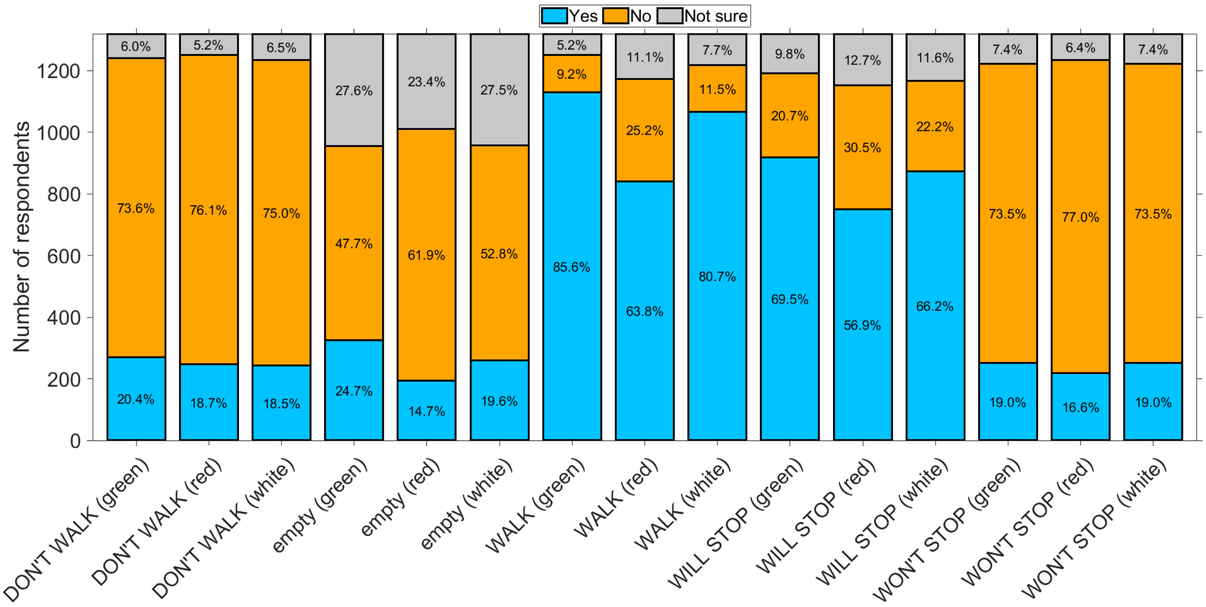


Figure 7. Distribution of answers to the question "*Would you feel safe to cross in front of the car above?*".

As mentioned above, we filtered the respondents based on strict criteria regarding whether they selected the color of 80% of the concepts correctly. Figure A1 in the appendix shows the results before three levels of filtering, including a very strict filter where no mistakes in specifying the color of the display are allowed. It can be seen that the results are similar regardless of the strictness of the filter.

Table 2. Examples of answers to the question "*If you think that the message on the car above is unclear, please explain why below*" for eHMIs with no textual message.

Empty green	**Empty red**	**Empty white**
because of the green color I am inclined to think I can go on, but I am not so sure	because of the red color I am inclined to think that it is completely stopped, but I am not so sure	I have no idea what it is supposed to mean
There is no message, you have to refer that red means stop and green means walk	no message on the car and i dont know whats the colour means	The white lights may be taken as the usual car lights
I am afraid I don t understand the meaning for the first time	I don't know if I'm to move or to stop	There is no message on the car, just some white light.
It is not safe since it does not have an active message that indicates it	for whom is red?	There is no message that it is safe to cross.
The message on the car doesn't mean anything	There is not even a message on the display and the red color may represent some kind of warning.	I don't know what the white lights mean

Note. The number of comments out of 1,319 respondents was 444 for '*Empty green*', 433 for '*Empty red*', and 449 for '*Empty white*'. Typographical errors in the examples above were retained.

Comparisons between countries

Figure 8 shows the percentages of respondents who answered '*Yes*', as a function of the eHMI type, for the four most highly represented countries: Venezuela (n = 518), India (n = 79), United States (n = 75), and Ukraine (n = 51). It can be seen that there is a correlational similarity between responses from different countries ($r > 0.97$) and that ordinality is preserved. For example, the number of '*Yes*' responses for a white eHMI is generally higher than for a red eHMI but lower than for a green eHMI, regardless of country. However, it can be seen that there are biases in the overall number of '*Yes*' responses. Although India and Venezuela yielded similar '*Yes*' percentages (Fig. 8, left), respondents from the United States were more conservative overall, whereas in Ukraine respondents were relatively likely to cross the road even when the display was empty or instructed 'DON'T WALK'.

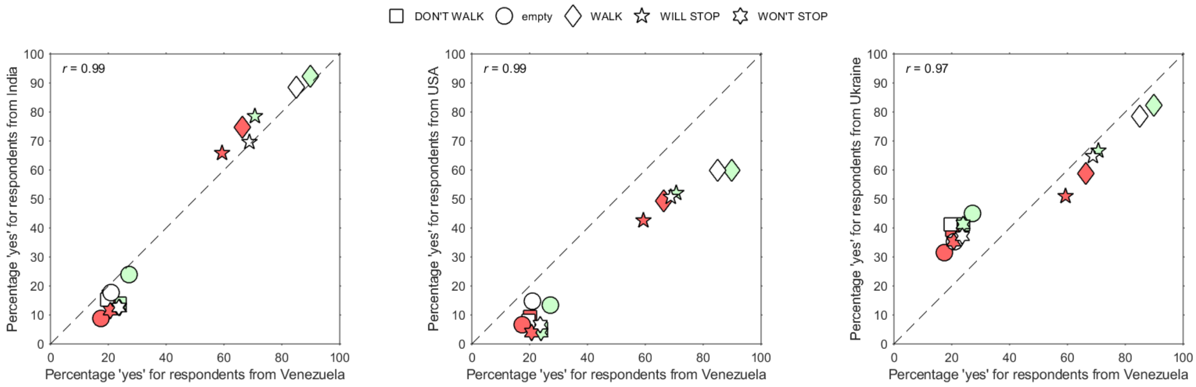


Figure 8. Percentages of respondents from four countries who answered '*Yes*' and '*Not sure*' as a function of the eHMI type.

4. Discussion

Future AVs may have to employ eHMIs to substitute or augment communication used today between human drivers and pedestrians. We performed two online surveys aiming to shed light on the clarity of eHMI concepts currently available from automotive companies (Survey 1) and to investigate the effects of text, color, and perspective on respondents' feeling of safety to cross the road (Survey 2).

Survey 1

Among the eHMIs presented by the industry, the eHMIs that combined (simple) textual instructions ('Go ahead', 'Waiting for You to Cross', 'Safe to Cross') with icons ('>' sign/eyes, pedestrian on zebra) received the highest clarity ratings. Textual eHMIs were found to be clearer by respondents from English-speaking countries than by respondents from countries in which English is not an official language, pointing towards language-related communication challenges.

Among the non-textual eHMIs, a projection of a zebra crossing, a representation that is already common on roads worldwide, was found to be the clearest. The clearest eHMI overall was a combination of text ('Go ahead') and anthropomorphic features (eyes), whereas the other eHMIs with anthropomorphic features received medium ratings, which may indicate that anthropomorphism alone is not commanding or convincing, in line with previous work on anthropomorphic versus non-anthropomorphic communication in robots (Burgoon et al., 2000; Fiore et al., 2013; Torta et al., 2012). The least understandable concept was a projection indicating the opening of a door. This finding does not imply that the specific message representation is unclear, but might be because this type of action is typically not communicated to road users in current traffic. Patent drawings were generally hard to understand, which may have been caused by their abstract nature. Summarizing, for non-textual signs, familiarity and literal representation were important contributors to the perceived clarity of these signs, in line with one of the dimensions identified by McDougall et al. (1999).

It is worth noting that up to 8% of respondents used the words 'sensor' or 'scanning' when describing the concepts. The use of the words 'sensor' or 'scanning' was especially prominent for light-based displays. Although all presented eHMIs require sensors that scan the environment, the eHMIs are not sensors themselves. The misperception of the function of eHMIs is indicative of shortcomings in the public's current understanding of AV technology. It can be expected that with the gradual introduction of AVs in the roads, future users will become increasingly aware of the functions of the AVs and better able to interpret what AVs can and cannot do. Knowledge is an important factor in improving the level of trust in and acceptance of AVs (Khastgir, Birrell, Dhadyalla, & Jennings, 2018).

Survey 2

The results of Survey 2 showed that a color-only eHMI is not informative without prior training. This is consistent with the results of Survey 1, in which clarity was perceived as higher for the displays containing text than for those that did not contain text, and with De Clercq et al. (2019), who compared textual and non-textual eHMIs and found that textual eHMIs were regarded as the least ambiguous and required no learning.

The most persuasive concept was the message 'WALK' in green color. For each of the five eHMI types, respondents felt safer to cross when the display was green instead of red, pointing towards an egocentric perspective or a familiarity heuristic (McDougall et al., 1999) rooted in the interpretation of current traffic lights. Among the textual eHMIs, the messages 'WALK' and 'WILL STOP' in red received the highest percentages of '*Not sure*' responses, likely due to the incongruence between the textual message giving priority to the pedestrian and the color red being interpreted from an egocentric perspective as an instruction to the pedestrian to not cross. Thus, our results suggest that a front brake light should be green instead of red, in line with how front brake lights were used by De Clercq et al. (2019) and Petzoldt, Schleinitz, and Banse (2018).

The effect of color was largest for the texts that permitted the pedestrian to cross ('WALK' and 'WILL STOP') and smaller for the texts that asked the pedestrian not to cross ('DON'T WALK' and 'WON'T STOP'). Not crossing can be seen as the default state of respondents, as indicated by the respondents' unwillingness to cross for the empty display. If the eHMI advised not to cross ('DON'T WALK' and 'WON'T STOP'), green did not persuade the respondents to cross, because the text message was in line with the default state. For the text messages 'WALK' and 'WILL STOP', green reinforced the crossing tendency, whereas red caused some uncertainty, indicated that respondents, on average, interpreted color from an egocentric perspective. To summarize, the text message was more dominant/persuasive than the color of the text; color acted as a 'reinforcer' of the message (or a source of confusion, if incongruent).

Strong correlational similarities ($r > 0.97$), but different response biases, were observed between selected countries, with, for example, respondents from Ukraine likely to feel safe to cross even when the eHMI indicated 'DON'T WALK'. These differences in a liberal versus conservative response strategy may relate to culture-specific effects and traffic rules. However, it cannot be ruled out that acquiescence bias ('yea-saying') is a cause of national differences in response style. This would be in line with our previous research, where we found that respondents from lower-income countries are more likely to give meaningless responses, possibly due to an English language barrier (Nordhoff, De Winter, Kyriakidis, Van Arem, & Happee, 2018). Regardless of these biases, the observed relative effects between eHMIs are regarded as robust (Fig. 8).

Limitations and recommendations for future research
A limitation of Survey 1 is that the message content (e.g., crossing, turning), scenarios, and traffic context differed between concepts, inhibiting a controlled investigation. For example, in some cases, only the eHMI was shown, whereas in other cases the response of pedestrians and/or cyclists was also illustrated; within the latter category, it was not always defined whether the demonstrated behavior by the pedestrians/cyclists was the intended one. For example, while video animations of a concept are likely to demonstrate an appropriate reaction by pedestrians/cyclists, videos in real traffic (Light bar 1–3) could be regarded as more ambiguous. Also, the industry may develop concept cars with eHMIs not necessarily to present unambiguous AV-pedestrian interactions; the purpose may also be showcasing and branding, as pointed out in the Introduction. On the other hand, it can be argued that the industry is inclined to present their concepts in the media in the most favorable manner possible, and would avoid deliberately presenting ambiguous eHMIs. In Survey 1, we retained the original media format of each concept (image, video, or drawing) to receive opinions of the respondents on the representations offered by the industry.

This study focused on eHMI concepts from industry (Survey 1) together with a controlled evaluation of 15 text-based eHMI (Survey 2). We do not mean to suggest that the eHMIs that came out as clearest in Surveys 1 and 2 are the clearest concepts overall. Academia has developed various additional concepts, including eHMIs on the roof of the car (Deb et al., 2019; Eisma et al., 2019; Vlakveld & Kint, 2019) as well as sound-based eHMIs (Mahadevan et al., 2018). It would be interesting to compare the existing academic concepts in a separate crowdsourcing study or meta-analysis.

A limitation of Survey 2 is that the eHMI concepts were presented on a photo of an AV driving in Delft, The Netherlands (Fig. 5), an environment that might be unfamiliar to respondents from different parts of the world. Another limitation of Survey 2 is that the eHMIs were shown in static images. We opted for images instead of videos to rule out the effect of implicit cues such as relative speed and distance. For future research, it would be relevant to test eHMIs in dynamic situations, as the effectiveness of eHMIs may depend on relative distance and speed between the pedestrian and the AV. Another limitation is that we did not examine the effect of learning. Novel signs will likely become effective after some training (Chan & Ng, 2010; Goonetilleke et al., 2001). Finally, textual eHMIs in English may not be legible for illiterate people, children, or people who do not speak English.

Online questionnaires have been used before for measuring pedestrian receptivity towards automated cars (Deb et al., 2017) and for acquiring people's opinion about human-machine interfaces for assisting road users (Bazilinskyy, Petermeijer, Petrovych, Dodou, & De Winter, 2018; De Angelis et al., 2018). Nonetheless, a limitation remains that our eHMIs were not tested in real traffic. While the respondents found textual eHMIs the clearest, text might not be the best option in traffic with high visual demands. Specifically, it may take too much time to read a text message, whereas pedestrians could detect lights using their peripheral vision. A textual eHMI also requires a display with a sufficiently large surface area and high contrast to be legible from a distance (Clamann et al., 2017). Still, legibility of text may be a problem especially in rainy weather, see Rodríguez Palmeiro et al. 2018). Colored lamps, on the other hand, are easier to embed in the current design of cars and do not have to be large (cf. current blinkers). Finally, text may still have to be accompanied by a universal symbol to support pedestrians with different language capabilities, including children.

Also, we cannot conclude yet that an egocentric perspective should be adopted in real traffic. As mentioned in the introduction, a number of recommendations in the literature state that an allocentric perspective should be used and that an AV should not instruct others what to do (Cefkin, 2018; Volvo Cars, 2018a) but only display its own current state (Joisten et al., 2019) or target state (e.g., Deb et al., 2016). The use of egocentric eHMIs may be confusing or even dangerous in real traffic if multiple pedestrians are present: in such cases, it might be unclear to which pedestrian(s) the message refers, and directional communication (Dietrich et al., 2018) or allocentric messages may be a suitable alternative. This confusion may also have legal implications, as a message such as ‘Walk’ could cause a pedestrian to walk while he/she should not (e.g., in case of undetected traffic approaching from the opposite direction). Then again, current traffic lights at pedestrian crossings also contain egocentric signage (e.g., green walking figure). Another factor is that eHMIs with allocentric messages (e.g., ‘Braking’, ‘Will stop’) are more straightforward to develop than egocentric messages (e.g., ‘Walk’) because the latter requires that the AV is equipped with sensors and algorithms for pedestrian recognition.

This paper attempted to answer the question of which types of eHMI are clear to and interpretable by pedestrians. In summary, our present findings together with the existing literature form a dilemma: although egocentric textual eHMIs (e.g., ‘WALK’) are common among concept cars and regarded as clear and effective (see also De Clercq et al., 2019; Fridman et al., 2019), they have disadvantages regarding legibility, liability, and technical feasibility. It therefore remains doubtful whether egocentric textual eHMIs will ever find their way onto the market. Further research in dynamic environments and naturalistic contexts is required before conclusions can be drawn about the optimal design principles for eHMIs.

Acknowledgment
This research is supported by grant 016.Vidi.178.047 (2018–2022; "How should automated vehicles communicate with other road users?"), which is financed by the Netherlands Organisation for Scientific Research (NWO). We thank Ana Rodriguez Palmeiro for providing us with the photo and for initial work in this area of research.

References

Ackermann, C., Beggiato, M., Bluhm, L. F., Löw, A., & Krems, J. F. (2019). Deceleration parameters and their applicability as informal communication signal between pedestrians and automated vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour*, *62*, 757–768. https://doi.org/10.1016/j.trf.2019.03.006

Ackermann, C., Beggiato, M., Schubert, S., & Krems, J. F. (2019). An experimental study to investigate design and assessment criteria: what is important for communication between pedestrians and automated vehicles? *Applied Ergonomics*, *75*, 272–282. https://doi.org/10.1016/j.apergo.2018.11.002

AlAdawy, D., Glazer, M., Terwilliger, J., Schmidt, H., Domeyer, J., Mehler, B., Reimer, B., & Fridman, L. (2019). Eye contact between pedestrian and drivers [preprint]. Retrieved from https://www.researchgate.net/publication/332300079_Eye_Contact_Between_Pedestrians_and_Drivers

AutoMotoTV. (2015a). Mercedes-Benz F 015 Luxury in Motion - Interaction pedestrian stop parking. Retrieved from https://www.youtube.com/watch?v=FnU6gZ6LIAo

AutoMotoTV. (2015b). Mercedes-Benz F 015 Luxury in Motion - Interaction zebra crossing. Retrieved from https://www.youtube.com/watch?v=fvtlobbMENo

Avtanski, A. (2018). LCD display generator. Retrieved from http://avtanski.net/projects/lcd

Barbosa, N. M., & Chen, M. (2019). Rehumanized crowdsourcing: a labeling framework addressing bias and ethics in machine learning. *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. New York, NY: ACM. https://doi.org/10.1145/3290605.3300773

Bazilinskyy, P., Petermeijer, S. M., Petrovych, V., Dodou, D., & De Winter, J. C. F. (2018). Take-over requests in highly automated driving: A crowdsourcing survey on auditory, vibrotactile, and visual displays. *Transportation Research Part F, 56*, 82–98. https://doi.org/10.1016/j.trf.2018.04.001

Benderius, O., Berger, C., & Lundgren, V. M. (2018). The best rated human-machine interface design for autonomous vehicles in the 2016 Grand Cooperative Driving Challenge. *IEEE Transactions on Intelligent Transportation Systems*, *19*, 1302–1307. https://doi.org/10.1109/TITS.2017.2749970

BMW. (2016). The ideas behind the BMW VISION NEXT 100. Retrieved from https://www.youtube.com/watch?v=SBaR0oqjWIo

Böckle, M.-P., Brenden, A. P., Klingegård, M., Habibovic, A., & Bout, M. (2017). SAV2P–Exploring the impact of an interface for shared automated vehicles on pedestrians' experience. *9th International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '17)*. Oldenburg, Germany. https://doi.org/10.1145/3131726.3131765

Burgoon, J. K., Bonito, J. A., Bengtsson, B., Cederberg, C., Lundeberg, M., & Allspach, L. (2000). Interactivity in human-computer interaction: A study of credibility, understanding, and influence. *Computers in Human Behavior*, *16*, 553–574. https://doi.org/10.1016/S0747-5632(00)00029-7

Caldwell, A. (2019). Why top automakers spend millions on concept cars they don't plan on making. Business Insider. Retrieved from https://www.businessinsider.com/automakers-spend-millions-on-concept-cars-they-dont-make-2019-4?international=true&r=US&IR=T

Car TV. (2016). BMW Vision Next 100 - INTERIOR. Retrieved from https://www.youtube.com/watch?v=nljCUEzDXMU

Carter, E. J., Mistry, M. N., Carr, G. P. K., Kelly, B. A., & Hodgins, J. K. (2014). Playing catch with robots: Incorporating social gestures into physical interactions. *Proceedings of the 23rd IEEE International Symposium on Robot and Human Interactive Communication* (pp. 231–236). Edinburg, UK. https://doi.org/10.1109/ROMAN.2014.6926258

Cassell, J., Sullivan, J., Churchill, E., & Prevost, S. (Eds.). (2000). *Embodied conversational agents*. Cambridge: MIT Press.

Cefkin, M. (2018). Towards socially acceptable autonomous driving. Retrieved from https://wardsauto.informa.com/wp-content/uploads/morning-center-stage-nissan-cefkin.pdf

Cefkin, M., Zhang, J., Stayton, E., & Vinkhuyzen, E. (2019). Multi-methods research to examine external HMI for highly automated vehicles. In H. Krömker (Ed.), *HCI in Mobility, Transport, and Automotive Systems. HCII 2019. Lecture Notes in Computer Science (vol. 11596)* (pp. 46–64). Cham: Springer. https://doi.org/10.1007/978-3-030-22666-4_4

Chan, A. H., & Ng, A. W. (2010). Effects of sign characteristics and training methods on safety sign training effectiveness. *Ergonomics*, *53*, 1325–1346. https://doi.org/10.1080/00140139.2010.524251

Chang, C.-M., Toda, K., Sakamoto, D., & Igarashi, T. (2017). Eyes on a car: an interface design for communication between an autonomous car and a pedestrian. *Proceedings of the 9th ACM International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 65–73). Oldenburg, Germany. https://doi.org/10.1145/3122986.3122989

Clamann, M., Aubert, M., & Cummings, M. L. (2017). Evaluation of vehicle-to-pedestrian communication displays for autonomous vehicles. *Proceedings of the Transportation Research Board 96th Annual Meeting.* Washington DC.

Cowell, A. J., & Stanney, K. M. (2005). Manipulation of non-verbal interaction style and demographic embodiment to increase anthropomorphic computer character credibility. *International Journal of Human-Computer Studies*, *62*, 281–306. https://doi.org/10.1016/j.ijhcs.2004.11.008

Daimler. (2017). Autonomous concept car smart vision EQ fortwo: Welcome to the future of car sharing. Retrieved from https://media.daimler.com/marsMediaSite/en/instance/ko/Autonomous-concept-car-smart-vision-EQ-fortwo-Welcome-to-the-future-of-car-sharing.xhtml?oid=29042725

Dalrymple-Alford, E. C. (1972). Associative facilitation and interference in the Stroop color-word task. *Perception & Psychophysics*, *11*, 274–276. https://doi.org/10.3758/BF03210377

Davies, S., Haines, H., Norris, B., & Wilson, J. R. (1998). Safety pictograms: are they getting the message across? *Applied Ergonomics*, *29*, 15–23. https://doi.org/10.1016/S0003-6870(97)00021-5

De Angelis, M., Fraboni, F., Prati, G., Giusino, D., Depolo, M., Zani, B., ... & Johnson, D. (2018). Preferences of European cyclists towards passive and active systems with audio-visual and with handlebar vibration warnings. *Human Factors and Ergonomics Society Europe Chapter 2018 Annual Conference*. Berlin, Germany.

De Clercq, G. K., Dietrich, A., Núñez Velasco, P., De Winter, J. C. F., & Happee, R. (2019). External human-machine interfaces on automated vehicles: Effects on pedestrian crossing decisions. *Human Factors*. https://doi.org/10.1177/0018720819836343

De Visser, E. J., Monfort, S. S., McKendrick, R., Smith, M. A., McKnight, P. E., Krueger, F., & Parasuraman, R. (2016). Almost human: Anthropomorphism increases trust resilience in cognitive agents. *Journal of Experimental Psychology: Applied*, *22*, 331–349. https://doi.org/10.1037/xap0000092

Deb, S., Hudson, C. R., Carruth, D. W., & Frey, D. (2018). Pedestrians receptivity in autonomous vehicles: Exploring a video-based assessment. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 62*, 2061–2065. https://doi.org/10.1177/1541931218621465

Deb, S., Strawderman, L., & Carruth, D. W. (2019). Should I cross? Evaluating interface options for autonomous vehicle and pedestrian interaction. Proceedings of the Road, Safety, and Simulation Conference. Iowa City, IA.

Deb, S., Strawderman, L., Carruth, D. W., DuBien, J., Smith, B., & Garrison, T. M. (2017). Development and validation of a questionnaire to assess pedestrian receptivity toward fully autonomous vehicles. *Transportation Research Part C: Emerging Technologies, 84*, 178–195. https://doi.org/10.1016/j.trc.2017.08.029

Deb, S., Strawderman, L. J., & Carruth, D. W. (2018). Investigating pedestrian suggestions for external features on fully autonomous vehicles: A virtual reality experiment. *Transportation Research Part F: Traffic Psychology and Behaviour*, *59*, 135–149. https://doi.org/10.1016/j.trf.2018.08.016

Deb, S., Warner, B., Poudel, S., & Bhandari, S. (2016). Identification of external design preferences in autonomous vehicles. In H. Yang, Z. Kong, & M. D. Sarder (Eds.), *Proceedings of the 2016 Industrial and Systems Engineering Research Conference* (pp. 69–44). Anaheim, CA: IISE.

Dey, D., & Terken, J. (2017). Pedestrian interaction with vehicles: roles of explicit and implicit communication. *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 109–113). New York, NY: ACM. https://doi.org/10.1145/3122986.3123009

Dietrich, A., Willrodt, J.-H., Wagner, K., & Bengler, K. (2018). Projection-based external human-machine interfaces – Enabling interaction between automated vehicles and pedestrians. *Proceedings of the Driving Simulation Conference Europe* (pp. 43–50). Antibes, France.

drive.ai. (2018). drive.ai. Retrieved from https://www.drive.ai/

Eisma, Y. B., Van Bergen, S., Ter Brake, S. M., Hensen, M. T. T., Tempelaar, W. J., & De Winter, J. C. F. (2019). External human-machine interfaces: The effect of display location on crossing intentions and eye-movements. Retrieved from https://www.researchgate.net/publication/336471211_External_human-machine_interfaces_The_effect_of_display_location_on_crossing_intentions_and_eye_movements

Ekman, P., & Friesen, W. V. (1969). The repertoire of nonverbal behavior: Categories, origins, usage, and coding. *Semiotica*, *1*, 49–98. https://doi.org/10.1515/semi.1969.1.1.49

Ells, J. G., & Dewar, R. E. (1979). Rapid comprehension of verbal and symbolic traffic sign messages. *Human Factors*, *21*, 161–168. https://doi.org/10.1177/001872087902100203

Epley, N., Keysar, B., Van Boven, L., & Gilovich, T. (2004). Perspective taking as egocentric anchoring and adjustment. *Journal of Personality and Social Psychology*, *87*, 327–339. https://doi.org/10.1037/0022-3514.87.3.327

Epley, N., Waytz, A., & Cacioppo, J. T. (2007). On seeing human: a three-factor theory of anthropomorphism. *Psychological Review*, *114*, 864–886. http://dx.doi.org/10.1037/0033-295X.114.4.864

Färber, B. (2016). Communication and communication problems between autonomous vehicles and human drivers. In M. Maurer, J. Gerdes, B. Lenz, & H. Winner (Eds.), *Autonomous driving* (pp. 125–144). Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-662-48847-8_7

Fiore, S. M., Wiltshire, T. J., Lobato, E. J., Jentsch, F. G., Huang, W. H., & Axelrod, B. (2013). Toward understanding social cues and signals in human-robot interaction: effects of robot gaze and proxemic behavior. *Frontiers in Psychology*, *4*, 859. https://doi.org/10.3389/fpsyg.2013.00859

Ford Media Center. (2017). Ford, Virginia Tech go undercover to develop signals that enable autonomous vehicles to communicate with people. Retrieved from https://media.ford.com/content/fordmedia/fna/us/en/news/2017/09/13/ford-virginia-tech-autonomous-vehicle-human-testing.html

Fridman, L., Mehler, B., Xia, L., Yang, Y., Facusse, L. Y., & Reimer, B. (2019). To walk or not to walk: Crowdsourced assessment of external vehicle-to-pedestrian displays. *Proceedings of Transportation Research Board Annual Meeting*. Washington, DC.

Golson, J. (2016). Drive.ai wants to help autonomous cars talk with the people around them. Retrieved from https://www.theverge.com/2016/8/30/12700290/drive-ai-autonomous-car-human-robot-interface

Goonetilleke, R. S., Martins Shih, H., On, H. K., & Fritsch, J. (2001). Effects of training and representational characteristics in icon design. *International Journal of Human-Computer Studies*, *55*, 741–760. https://doi.org/10.1006/ijhc.2001.0501

Habibovic, A., Andersson, J., Lundgren, V. M., Klingegård, M., Englund, C., & Larsson, S. (2018a). External vehicle interfaces for communication with other road users? In G. Meyer & S. Beiker (Eds.), *Automated Vehicles Symposium 2018* (pp. 91–102). Cham: Springer. https://doi.org/10.1007/978-3-319-94896-6_9

Habibovic, A., Lundgren, V. M., Andersson, J., Klingegård, M., Lagström, T., Sirkka, A., ... & Saluäär, D. (2018b). Communicating intent of automated vehicles to pedestrians. *Frontiers in Psychology*, *9*, 1336. https://doi.org/10.3389/fpsyg.2018.01336

Hensch, A. C., Neumann, I., Beggiato, M., Halama, J., & Krems, J. F. (2019). How should automated vehicles communicate?–Effects of a light-based communication approach in a Wizard-of-Oz study. In N. Stanton (Ed.), *Advances in Human Factors of Transportation. AHFE 2019. Advances in Intelligent Systems and Computing (vol. 964)* (pp. 79–91). Cham: Springer. https://doi.org/10.1007/978-3-030-20503-4_8

Huang, S. C., & Bias, R. G. (2012). Without context, icons are significantly worse than texts to convey meanings in terms of accuracy and efficiency. *Proceedings of the ASIS&T 75th Annual Meeting*. Baltimore, MD.

Huang, Y., & Bai, Y. (2014). Effectiveness of graphic-aided portable changeable message signs in reducing

vehicle speeds in highway work zones. *Transportation Research Part C: Emerging Technologies*, *48*, 311–321. https://doi.org/10.1016/j.trc.2014.09.007
Hudson, C. R., Deb, S., Carruth, D. W., McGinley, J., & Frey, D. (2019). Pedestrian perception of autonomous vehicles with external interacting features. In I. Nunes (Ed.), *Advances in Human Factors and Systems Interaction. AHFE 2018. Advances in Intelligent Systems and Computing (vol. 781)* (pp. 33–39). Cham: Springer. https://doi.org/10.1007/978-3-319-94334-3_5
Jacobs, R. J., Johnston, A. W., & Cole, B. L. (1976). The visibility of alphabetic and symbolic traffic signs: Australian Road Research, May 1975, 5.7, 68–86. *Applied Ergonomics, 7*, 113. https://doi.org/10.1016/0003-6870(76)90184-8
Jaguar Land Rover. (2018). The virtual eyes have it. Retrieved from https://www.jaguarlandrover.com/2018/virtual-eyes-have-it
Joisten, P., Alexandi, E., Drews, R., Klassen, L., Petersohn, P., Pick, A., ... & Abendroth, B. (2019). Displaying vehicle driving mode–Effects on pedestrian behavior and perceived safety. In T. Ahram, W. Karwowski, S. Pickl, & R. Taiar (Eds.), *Human Systems Engineering and Design II. IHSED 2019. Advances in Intelligent Systems and Computing (vol 1026)* (pp. 250–256). Cham: Springer. https://doi.org/10.1007/978-3-030-27928-8_38
Kandil, F. I., Olk, B., & Hilgetag, C. C. (2017). Female vs. male Ampelmännchen: gender-specific reaction times to male and female traffic light figures. *Frontiers in Psychology*, *8*, 690. https://doi.org/10.3389/fpsyg.2017.00690
Keysar, B. (2007). Communication and miscommunication: The role of egocentric processes. *Intercultural Pragmatics*, *4*, 71–84. https://doi.org/10.1515/IP.2007.004
Keysar, B., & Barr, D. J. (2002). Self-anchoring in conversation: Why language users do not do what they 'should'. In T. Gilovich, D. Griffin, & D. Kahneman (Eds.), *Heuristics and biases: The psychology of intuitive judgment* (pp. 150–166). New York, NY, US: Cambridge University Press. https://doi.org/10.1017/CBO9780511808098.010
Keysar, B., Barr, D. J., & Horton, W. S. (1998). The egocentric basis of language use: Insights from a processing approach. *Current Directions in Psychological Science*, *7*, 46–49. https://doi.org/10.1111/1467-8721.ep13175613
Khastgir, S., Birrell, S., Dhadyalla, G., & Jennings, P. (2018). Calibrating trust through knowledge: Introducing the concept of informed safety for automation in vehicles. *Transportation Research Part C: Emerging Technologies*, *96*, 290–303. https://doi.org/10.1016/j.trc.2018.07.001
Kiesler, S., Siegel, J., & McGuire, T. W. (1984). Social psychological aspects of computer-mediated communication. *American Psychologist*, *39*, 1123–1134. https://doi.org/10.1037/0003-066X.39.10.1123
Klein, G. S. (1964). Semantic power measured through the interference of words with color-naming. *The American Journal of Psychology*, *77*, 576–588. https://doi.org/10.2307/1420768
Kline, T. J. B., Ghali, L. M., Kline, D. W., & Brown, S. (1990). Visibility distance of highway signs among young, middle-aged, and older observers: Icons are better than text. *Human Factors*, *32*, 609–619. https://doi.org/10.1177/001872089003200508
Knapp, M. L. (1980). *Essentials of nonverbal communication*. New York: Holt, Rinehart and Winston.
Krampen, M. (1965). Signs and symbols in graphic communication. *Design Quarterly, 62*, 1–31. https://doi.org/10.2307/4047303
Krampen, M. (1983). Icons of the road. *Semiotica, 43*, 1–204. https://doi.org/10.1515/semi.1983.43.1-2.1
Lagstrom, T., & Lundgren, V. M. (2015). *AVIP-Autonomous vehicles interaction with pedestrians* (Master of Science thesis). Chalmers University of Technology.
Lee, J. G., Kim, K. J., Lee, S., & Shin, D. H. (2015). Can autonomous vehicles be safe and trustworthy? Effects of appearance and autonomy of unmanned driving systems. *International Journal of Human-Computer Interaction, 31*, 682–691. https://doi.org/10.1080/10447318.2015.1070547
Leggett, T. (2018). What's the point of concept cars? BBC News. Retrieved from https://www.bbc.com/news/business-45900484
Lidwell, W., Holden, K., & Butler, J. (2003). *Universal principles of design.* Gloucester, MA: Rockport.
Löcken, A., Wintersberger, P., Frison, A.-K.,& Riener, A. (2019). Investigating user requirements for communication between automated vehicles and vulnerable road users. *Proceedings of the 2019 IEEE Intelligent Vehicles Symposium*. Paris, France. https://doi.org/10.1109/IVS.2019.8814027
Lodding, K. N. (1983). Iconic interfacing. *IEEE Computer Graphics and Applications*, *3*, 11–20. https://doi.org/10.1109/MCG.1983.262982
Lundgren, V. M., Habibovic, A., Andersson, J., Lagström, T., Nilsson, M., Sirkka, A., ... & Saluäär, D. (2017). Will there be new communication needs when introducing automated vehicles to the urban context? In N. Stanton, S. Landry, G. di Bucchianico, & A. Vallicelli (Eds.), *Advances in Human Aspects of Transportation. Advances in Intelligent Systems and Computing (vol. 484)* (pp. 485–497). Cham: Springer. http://doi.org/10.1007/978-3-319-41682-3_41

Mahadevan, K., Somanath, S., & Sharlin, E. (2018). Communicating awareness and intent in autonomous vehicle-pedestrian interaction. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, paper 429. https://doi.org/10.1145/3173574.3174003

Matthews, M., Chowdhary, G., & Kieson, E. (2017). Intent communication between autonomous vehicles and pedestrians. *ArXiv Preprint:1708.07123*.

McDougall, S. J., Curry, M. B., & De Bruijn, O. (1999). Measuring symbol and icon characteristics: Norms for concreteness, complexity, meaningfulness, familiarity, and semantic distance for 239 symbols. *Behavior Research Methods, Instruments, & Computers*, *31*, 487–519. https://doi.org/10.3758/BF03200730

Mehrabian, A. (1972). *Nonverbal communication.* Chicago: Aldine-Atherton.

Mercedes-Benz. (2015). The Mercedes-Benz F 015 Luxury in Motion. Retrieved from https://www.mercedes-benz.com/en/mercedes-benz/innovation/research-vehicle-f-015-luxury-in-motion

Mercedes-Benz USA. (2015). Mercedes-Benz F 015 Luxury in Motion. Retrieved from https://www.youtube.com/watch?v=MaGb3570K1U

Mirnig, N., Perterer, N., Stollnberger, G., & Tscheligi, M. (2017). Three strategies for autonomous car-to-pedestrian communication: A survival guide. *Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction* (pp. 209–210). Vienna, Austria. https://doi.org/10.1145/3029798.3038402

Mitsubishi Electric. (2015). Mitsubishi Electric introduces road-illuminating directional indicators. Retrieved from http://www.mitsubishielectric.com/news/2015/1023.html

Mulligan, B. (1936). *Collisions in street and highway transportation*. Philadelphia: Dorrance, Inc.

Nissan. (2015). IDS Concept. Retrieved from https://www.nissan.co.uk/experience-nissan/concept-cars/ids-concept.html

Nordhoff, S., De Winter, J. C. F., Kyriakidis, M., Van Arem, B., & Happee, R. (2018). Acceptance of driverless vehicles: Results from a large cross-national questionnaire study. *Journal of Advanced Transportation*, Article ID 5382192. https://doi.org/10.1155/2018/5382192

Oliveira, L., Proctor, K., Burns, C. G., & Birrell, S. (2019). Driving style: how should an automated vehicle behave? *Information*, *10*, 219. https://doi.org/10.3390/info10060219

Pennycooke, N. (2012). AEVITA: *Designing biomimetic vehicle-to-pedestrian communication protocols for autonomously operating & parking on-road electric vehicles* (Doctoral dissertation). Massachusetts Institute of Technology.

Peters, A. (2016). This self-driving car smiles at pedestrians to let them know it's safe to cross. Retrieved from https://www.fastcompany.com/3063717/this-self-driving-car-smiles-at-pedestrians-to-let-them-know-its-safe-to-cross

Petzoldt, T., Schleinitz, K., & Banse, R. (2018). Potential safety effects of a frontal brake light for motor vehicles. *IET Intelligent Transport Systems, 12*, 449. https://doi.org/10.1049/iet-its.2017.0321

Purchase, H. (1998). Defining multimedia. *IEEE Multimedia*, *5*, 8–15.

Redding, H. (2017). Here's why automakers build concept cars. Ridestory. Retrieved from http://ridestory.com/2017/07/05/heres-why-automakers-build-concept-cars/#.XcXtRTNKiHs

Reeves, B., & Nass, C. I. (1996). *The media equation: How people treat computers, television, and new media like real people and places*. New York, NY: Cambridge University Press.

Rinspeed AG. (2017). 2017 Rinspeed Oasis. Retrieved from https://www.rinspeed.eu/en/Oasis_21_concept-car.html

Rodríguez Palmeiro, A., Van der Kint, S., Vissers, L., Farah, H., De Winter, J. C. F., & Hagenzieker, M. (2018). Interaction between pedestrians and automated vehicles: A Wizard of Oz experiment. *Transportation Research Part F: Traffic Psychology and Behaviour*, 58, 1005-1020. https://doi.org/10.1016/j.trf.2018.07.020

Rogers, Y. (1989). Icons at the interface: their usefulness. *Interacting with Computers*, *1*, 105–117. https://doi.org/10.1016/0953-5438(89)90010-6

Salem, M., Eyssel, F., Rohlfing, K., Kopp, S., & Joublin, F. (2011). Effects of gesture on the perception of psychological anthropomorphism: a case study with a humanoid robot. *Proceedings of the International Conference on Social Robotics* (pp. 31–41). Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-25504-5_4

Schieben, A., Wilbrink, M., Kettwich, C., Madigan, R., Louw, T., & Merat, N. (2019). Designing the interaction of automated vehicles with other traffic participants: design considerations based on human needs and expectations. *Cognition, Technology & Work, 21*, 69–85. https://doi.org/10.1007/s10111-018-0521-z

Schmidt, H., Terwilliger, J., AlAdawy, D., & Fridman, L. (2019). Hacking nonverbal communication between pedestrians and vehicles in virtual reality. *arXiv preprint arXiv:1904.01931*.

Semcon (2016). Who sees you when the car drives itself? Retrieve from https://semcon.com/smilingcar/

Shinar, D., & Vogelzang, M. (2013). Comprehension of traffic signs with symbolic versus text displays. *Transportation Research Part F: Traffic Psychology and Behaviour*, *18*, 72–82.

https://doi.org/10.1016/j.trf.2012.12.012
Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643–662. https://doi.org/10.1037/h0054651
Šucha, M. (2014). Road users' strategies and communication: Driver-pedestrian interaction. *Proceedings of the Transport Research Arena (TRA) 5th Conference: Transport Solutions from Research to Deployment*. Paris, France.
Sweeney, M., Pilarski, T., Ross, W. P., & Liu, C. (2018). Light output system for a self-driving vehicle (Patent No. US9902311B2). US Patent Office.
Taylor, F. V., & Garvey, W. D. (1959). The limitations of a 'Procrustean' approach to the optimization of man-machine systems. *Ergonomics*, *2*, 187–194. https://doi.org/10.1080/00140135908930424
Torta, E., Van Heumen, J., Cuijpers, R. H., & Juola, J. F. (2012). How can a robot attract the attention of its human partner? A comparative study over different modalities for attracting attention. *Proceedings of the International Conference on Social Robotics* (pp. 288–297). Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-34103-8_29
Toyota. (2018). Concept-i. Retrieved from https://newsroom.toyota.eu/2018-toyota-concept-i
Urmson, C. P., Mahon, I. J., Dolgov, D. A., & Zhu, J. (2015). Pedestrian notifications (Patent No. US8954252B1). US Patent Office.
Viganò, R., & Rovida, E. (2015). A proposed method about the design of road signs. *Journal of Transportation Safety & Security*, *7*, 56–75. https://doi.org/10.1080/19439962.2014.902413
Vlakveld, W. P., & Kint, S. (2019). *Hoe reageren fietsers op zelfrijdende auto's?: gedragsintenties bij ontmoetingen op kruispunten* [How do cyclists react to self-driving cars ?: behavioral intentions at encounters at intersections] (Report No. R-2018-21). SWOV – Instituut voor Wetenschappelijk Onderzoek Verkeersveiligheid.
Volvo Cars. (2018a). Volvo 360c concept calls for universal safety standard for autonomous car communication. Retrieved from https://www.media.volvocars.com/global/en-gb/media/pressreleases/237019/volvo-360c-concept-calls-for-universal-safety-standard-for-autonomous-car-communication1
Volvo Cars. (2018b). The 360c: 360° safety. Retrieved from https://www.youtube.com/watch?v=H5KNPQT72FA
Waymo (2019). On the road. Retrieved from https://waymo.com/ontheroad
Waytz, A., Heafner, J., & Epley, N. (2014). The mind in the machine: Anthropomorphism increases trust in an autonomous vehicle. *Journal of Experimental Social Psychology*, *52*, 113–117. https://doi.org/10.1016/j.jesp.2014.01.005
Webb, J. M., Sorenson, P. F., & Lyons, N. P. (1989). An empirical approach to the evaluation of icons. *ACM SIGCHI Bulletin*, *21*, 87–90. https://doi.org/10.1145/67880.67894
Werner, A. (2018). New colours for autonomous driving: an evaluation of chromaticities for the external lighting equipment of autonomous vehicles. *Colour Turn, III*. https://doi.org/10.25538/tct.v0i1.692
Zhang, J., Vinkhuyzen, E., & Cefkin, M. (2017). Evaluation of an autonomous vehicle external communication system concept: a survey study. In N. Stanton (Eds.), *Advances in Human Factors and Systems Interaction. AHFE 2018. Advances in Intelligent Systems and Computing (vol. 597)* (pp. 650–661). Cham: Springer. https://doi.org/10.1007/978-3-319-60441-1_63

Appendices

Appendix A

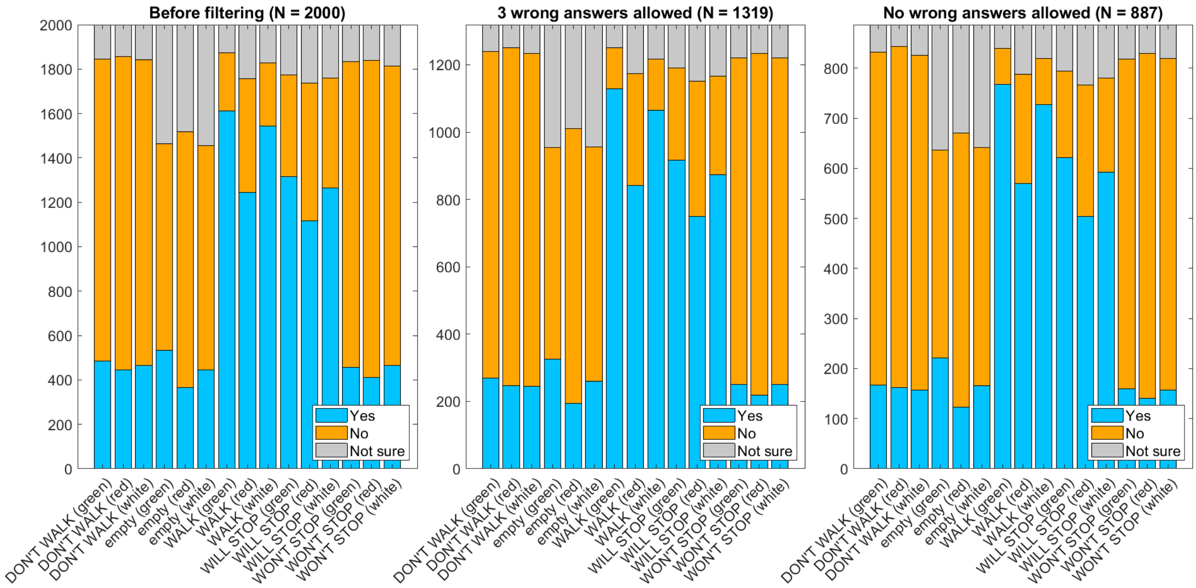


Figure A1. Distribution of answers to the question "*Would you feel safe to cross in front of the car above?*" before filtering of data (left), after less strict filtering (3 wrong answers allowed, center), and after very strict filtering (0 wrong answers allowed, right).

Appendix B. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.4121/uuid:9ea78136-3ffc-4194-84f7-3116b6a55758.