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Understanding the Messages Conveyed by Automated Vehicles

Yee Mun Lee
Ruth Madigan
Jorge Garcia
Andrew Tomlinson
Albert Solernou
Richard Romano
Gustav Markkula
Natasha Merat
University of Leeds,
Leeds, United Kingdom
y.m.lee@leeds.ac.uk

Jim Uttley
University of Sheffield,
Sheffield, United Kingdom
j.uttley@sheffield.ac.uk

ABSTRACT
Efficient and safe interactions between automated vehicles and other road users can be supported through external Human-Machine Interfaces (eHMI). The success of these interactions relies on the eHMI signals being adequately understood by other road users. A paired-comparison forced choice task (Task 1), and a 6-point rating task (Task 2) were used to assess the extent to which ten different eHMI signals conveyed three separate messages, 'I am giving way', 'I am in automated mode' and 'I will start moving'. The different eHMI options consisted of variations of a 360° lightband, a single lamp, and an auditory signal. Results demonstrated that the same eHMI format could convey different messages equally well, suggesting a need to be cautious when designing eHMI, to avoid presenting misleading, potentially unsafe, information. Future research should investigate whether the use of an eHMI signal indicating a change in the AV's behaviour is sufficient for conveying intention.

Author Keywords
eHMI; signal message; signal design; comprehension; automated vehicles

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CCS Concepts
• Human-centered computing --- Laboratory experiments; Virtual reality; Usability testing

INTRODUCTION
One of the key challenges associated with the development of automated vehicles (AVs) relates to their capacity to communicate and interact with other road users in a comprehensible and predictable manner, in the absence of a human driver [12]. In close encounters with conventional vehicles, pedestrians often look to the driver to understand if it is safe for them to cross [13, 30]. Thus, AV designers need to understand what explicit driver communication cues can be replaced, and how.

A number of studies have begun to make use of test-track and ghost-driver methodologies to investigate how vulnerable road users such as pedestrians and cyclists interact with automated vehicles. These studies have found that, in general, road users rely on the implicit cues provided by the vehicle to make a decision about whether to cross [5, 16, 28]. However, the use of explicit communication cues may be important in ensuring that pedestrians' feel comfortable moving around these vehicles, particularly in slow-moving situations [34], or in situations where there is uncertainty about vehicle's intent, or a mismatch between vehicle and "driver" behaviours [16, 28]. A questionnaire study by Merat et al. [24] provides support for this idea, by showing that pedestrians and cyclists, would like to receive communication about the status and behaviour of AVs, particularly about whether they have been detected, and that they would prefer to receive this communication through conventional communication channels such as lights and beeps rather than spoken word or text.

Different options for conveying AV intent are currently being explored. For example, manufacturers such as Mercedes-Benz, Nissan, and Google are considering external vehicle displays as a replacement for explicit driver communications, using auditory, light, and text-based signals to communicate with the external world [25, 26]. Researchers have also begun to consider different design concepts for conveying specific messages. For example, studies have shown that messages conveyed through the conventional walk / don't walk symbols (green and red walking silhouettes) or text-based messages can be successful in conveying messages about whether a vehicle is giving way [6, 11], although this information may be less important in road users decision making than speed and distance information [5].

When considering the design of external interfaces, Clamann et al. [5] draw attention to the visibility difficulties associated with portraying symbols and text messages on the front of a moving vehicle. They calculate that in order to be visible at 100 feet, a letter would need to be at least six inches tall and 3.6 inches wide, while a symbol would need to be at least 14 inches tall to be readable from 200 feet. These size requirements make it difficult to implement these types of text- and symbol-based messages on fast moving vehicles.

In order to avoid these issues, some studies have considered the use of light-based signals to convey AV intent. For example, a series of wizard-of-oz studies by Habibovic and colleagues [14, 22] used a visual interface incorporating lights at the top of the windscreen to convey different messages. They found that after a short training course, participants deemed that the interface was easy to interpret. Participants also stated that they felt significantly less safe when they encountered the AV without the interface, compared to the conventional vehicle and the AV with the interface. A small scale prototype study by Mahadevan et al. [23] comparing the success of different coloured LED lights, animated faces, and auditory messages in conveying different messages to pedestrians, also found that the LED strip was ranked higher compared to other auditory and physical cues. However, there was some concern that the use of four different LED colours with different meanings could cause confusion. These results suggest that a light-based interface could contribute to a positive experience and improved perceived safety in pedestrian encounters with AVs. However, an experimental study by Ackermann et al. [2] found that the meaning conveyed by LED light-strips was often misunderstood, when compared to text- and symbol-based messages. This finding led Ackermann et al. [2] to exclude LED lightstrips from their analysis of recognisability, unambiguousness and interaction comfort.

Another issue to consider is the positioning and colour of any external human machine interfaces (eHMI). Liu et al. [21] conducted an experiment to evaluate the visibility of different windscreen lamp arrangements from three different viewing angles in a car-park setting. They found a significant rightward bias in the detection of low-luminosity amber lights on the windshield of AVs, but this bias disappeared for white lights. They interpret these results as suggesting that critical HMI components should be placed on the drivers' side of the vehicle to ensure that they are seen. This research suggests that the placement of any communication signals is an important consideration, and also highlights the visibility issues associated with coloured lights in particular. Research evaluating the most suitable chromatic range for eHMI has found that cyan scored highly in terms of visibility, saliency, and discriminability [37], and as a result many international consortia have adopted this as the colour of choice for conveying AV messages.

Current study

The aim of the current study was to gain a deeper understanding of whether different light- and sound-based eHMI signal designs can be successfully linked to specific AV messages. Given the design constraints outlined above, there is a need to develop solutions that can realistically be implemented on AV interfaces. Thus, there is a limited pool of potential design variants that can be used. This study provides a method for evaluating and comparing users' comprehension of these designs.

To date, the majority of studies have focused on conveying the message that it is either safe or not safe for the pedestrian to cross [2, 5, 6, 11]. However, there are dangers associated with providing explicit advice to other road users, who may run the risk of misinterpreting the message or may walk out in front of other traffic. For that reason, the focus in the current study was on providing information on the AV's intended behaviours, rather than providing instructions to other road users. Three different messages were selected for inclusion, based on an evaluation of practicality and feasibility [35]. Firstly the message "I am giving way" was selected to mirror the previous research investigating pedestrians' crossing decisions [5, 6, 11], and to target the desire of vulnerable road users (VRUs) to know whether they have been detected [24]. The second message selected was "I will start moving", which has been shown to be of importance in facilitating VRUs trust and acceptance of AVs [24]. Finally, the message "I am in automated mode" was identified as being of importance in supporting other traffic participants' development of correct expectations of AV behaviours [29].

To evaluate the impact of visibility and light positioning on participants evaluations of meaning, three types of visual eHMI design were investigated. A 360° LED light band which would be visible to road users in different positions around the vehicle, was compared to a single lamp/display on the front of the vehicle [35], and to the more conventional flashing of headlights often used by drivers in current on-road interactions [32]. In line with previous research about eHMI colour, the eHMI were displayed in cyan [37]. Finally, in order to facilitate communication with visually impaired groups, an auditory eHMI signal was also included. To avoid any language barriers, and any emotional association with particular sounds e.g. honking horns [8, 17] a neutral beeping sound was chosen. These eHMI options all provide examples of signals which can realistically be implemented on AVs, and which are likely to provide the required level of visibility in busy road environments.

In order to understand if these light and sound signals could be used to communicate specific AV messages, the different eHMI signal designs were firstly presented to participants in a paired-comparison method (Task 1). In this task, participants were asked to choose which eHMI design best conveyed particular messages. In a separate task, they were then required to rate to what extent each of these eHMI signal designs conveyed the desired message (Task 2). The combination of the two tasks enabled an evaluation of the most easily understood design variations from the pool of options available.

METHODS

Participants
Ethical approval was obtained from the University of Leeds Research Ethics Committee. Twenty participants (9 Females) took part in this study, with a mean age of 26.85 years (Range = 22 to 44; S.D. = 4.74). The study took an hour to complete, and participants were given £10 for their participation.

Apparatus
The study was conducted at the University of Leeds. There were two tasks within the study (see Design and Stimuli for descriptions). In Task 1, participants used a HTC VIVE head-mounted display (HMD) to view the AVs and eHMI options, and a handheld controller was used to provide responses (see Figure 1). Task 2 was displayed on a PC screen. Unity software was used to create the virtual environment, and the experimental set-up for both tasks, and participants wore headphones throughout.

Figure 1: The HTC VIVE head-mounted display (HMD) and the controller

Design and Stimuli
Obtaining evaluations of specific stimuli can easily be influenced by subjective bias [27]. Therefore, a converging operations approach i.e. using more than one method to address the same research question, was used to assess participant judgements about the use of different eHMI signals for communicating each AV message.

The study consisted of two tasks, both using a within-subjects design. Task 1 used a paired-comparison forced choice task, and Task 2 used a rating task. Ten eHMI signals were assessed on how successfully they communicated three different messages related to the behaviour or intention of the AV, specifically: ‘I am giving way’; ‘I am in automated mode’; and ‘I will start moving’.

External HMI Design Signals
The eHMI signal designs were either presented as an LED light band positioned along the front and sides of the vehicle (Figure 2a), a single lamp located at the position of the front mirror of the vehicle (Figure 2b), an auditory sound cue [3] or a conventional headlight flashing. These eHMIs were animated in different ways (Table 1), and the visual signal designs No. 1-6 and 10 were presented in cyan colour.

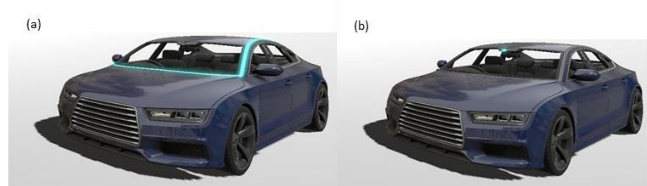

Figure 2. (a) Light band positioned along the front and sides of the vehicle (b) A single lamp located at the position of the front mirror of the vehicle

Signal Design No.	eHMI Form	eHMI Signal Design
1	Light Band	Fast Pulsing (2 Hz)
2	Light Band	Slow Pulsing (0.4 Hz)
3	Light Band	Filled from front to back (3 seconds)
4	Light Band	Filled from back to front (3 seconds)
5	Single Lamp	Fast Pulsing (2 Hz)
6	Single Lamp	Slow Pulsing (0.4 Hz)
7	Conventional Headlights	Flashing
8	Auditory	Fast (2 Hz)
9	Auditory	Slow (0.4 Hz)
10	Multiple-modality	Signal Design No. 1 + 8

Table 1. The 10 eHMI Signal Designs Presented on Vehicle

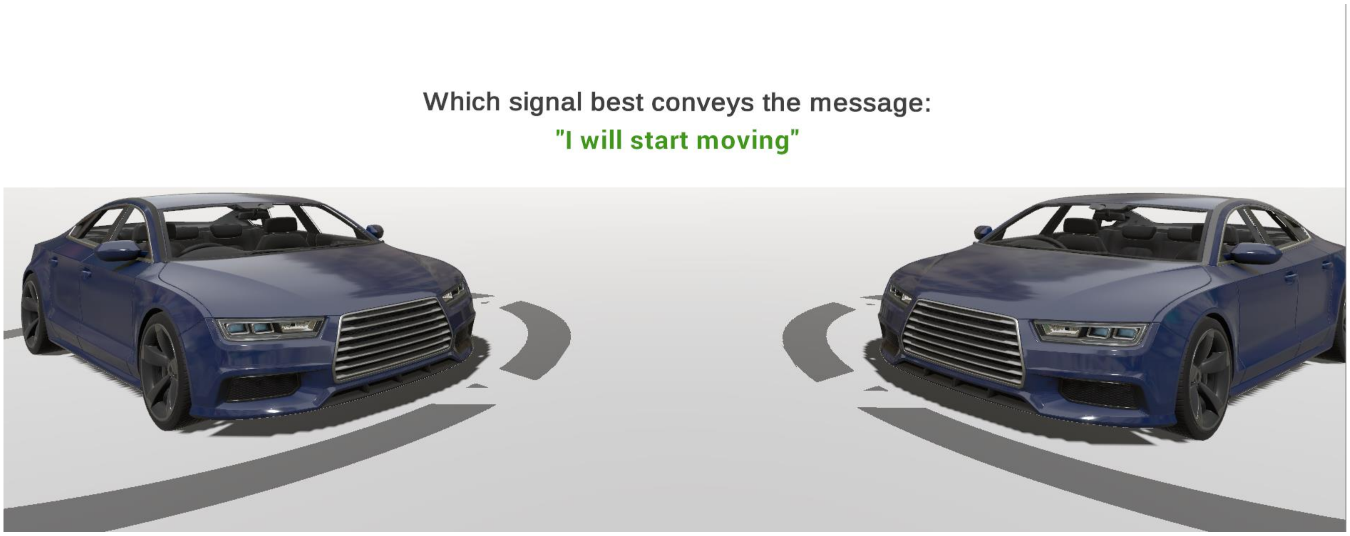

Figure 3: The experimental setup for the paired comparison forced choice task (Task 1)

Task 1: Paired-comparison forced choice task
Task 1 of the experiment adopted a paired-comparison forced choice task (Figure 3), in which participants had to choose which of two eHMI signal designs best conveyed one of the three intention messages being considered.

During each trial one of the three intention messages was displayed in the middle of the screen, as shown in Figure 3 and participants were asked to press a button to confirm they had read the message. Two vehicles displaying different eHMI signal designs were then presented side-by-side, but with a sufficient gap between them to require participants to turn their head to look at each one. When looking directly towards one of the vehicles a circle beneath it would turn orange to indicate it was 'active' and any sound they could hear (signal 8, 9 and 10) was from that vehicle. Participants were allowed to view the vehicles as many times, and as for long, as they wanted.

The participants' task was to choose which of the two signals best conveyed the message shown at the beginning of the trial. To confirm their decision, they had to look at the chosen vehicle and press the trigger button on the controller. The next trial/message would then appear in the middle of the space again.

135 trials were presented in total in Task 1 (3 messages, 45 eHMI signal design pairings), with each signal design being compared to every other option. The order in which each pairing and message was presented was counterbalanced following the method described by [36]. This ensured adequate distance between each appearance of a given signal, and ensured that each signal would appear on the left and right vehicle an approximately equal number of times.

Task 2: 6-point rating task
After completing Task 1, participants then carried out Task 2 of the study, which was a rating task, presented on a computer screen. 30 trials (3 messages and 10 eHMI signal designs) were presented to participants in a randomized order. Each trial presented an image of a vehicle showing one of the 10 eHMI signal designs. A question was also presented, asking the participant to rate how strongly they agreed or disagreed that the signal conveyed one of the three messages being investigated. A 6-point response scale was used, where 1 represented 'completely disagree' and 6 represented 'completely agree' (see Figure 4 for illustration).

Figure 4: The experimental setup for the 6-point rating task (Task 2)

Procedure

All participants took part in Tasks 1 and 2 of the study. During Task 1, they were asked to wear the HTC VIVE Head-mounted display. Participants were initially shown the VR environment (Figure 3) containing the grey circles without any vehicles. This allowed the experimenter to provide instructions to participants regarding what they would see and do before they saw any vehicle designs. To avoid fatigue, there was a short break after participants had completed half of the trials in Task 1. During this break, participants completed the Misery Scale [4], to ensure they did not feel unwell.

After completing Task 1, another Misery Scale was administered before participants commenced Task 2. At this point, participants were given instructions on Task 2 of the experiment. As it was a computer based task, they no longer had to wear the head-mounted display.

RESULTS

Due to a technical error, there were some missing data for each participant throughout the study. The number of responses to each comparison for each message ranged between 8 and 20, with a mean of 14 responses per comparison.

Task 1

Participants' responses in the paired comparisons task were analysed using the log-linear Bradley-Terry method, implemented in R (version 3.5.3) through the *prefmod* package [15]. This method allows analysis of data from incomplete paired comparison designs. A 'worth' estimate is calculated for each signal design as a measure of how strongly it was associated with the particular message being evaluated, relative to the other signal designs. These worth estimates are shown for each message in Figure 5. Paired contrasts were carried out using a bonferroni-corrected alpha (a = .0011) to assess whether differences in worth estimates between pairs of signals were significant.

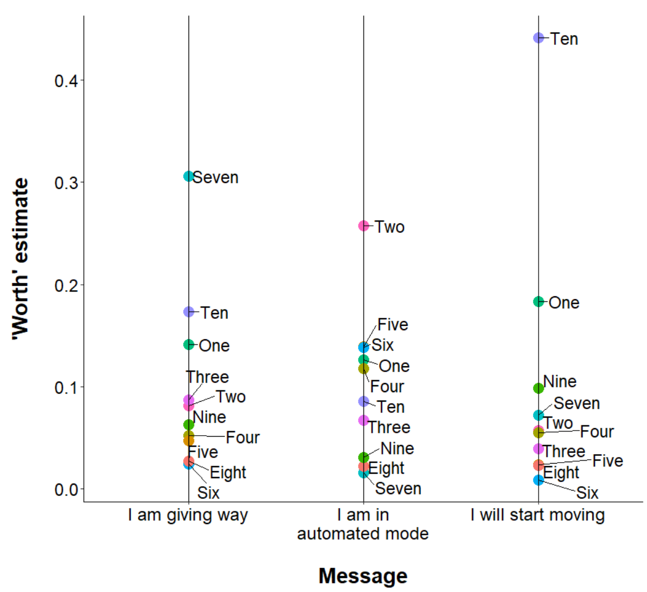

Figure 5. Worth estimates for each signal design (see Table 1 for signal design labels), as evaluated against the three messages. A larger worth estimate indicates a stronger association with that message, relative to the others included.

I am giving way

Results suggested signal design seven, flashing of conventional headlights, was a clear winner for conveying the message that the vehicle was giving way. Of the new signal designs not currently available on vehicles, signals ten (multi-modality – flashing light band and auditory signal) and one (fast-pulsing light band) were considered the best for conveying the message that the vehicle was giving way. There was little difference between other signals. Paired contrasts confirmed signal seven was significantly better than all other signals apart from signals one and ten. Signal ten was significantly better than signals four, five, eight and nine. Signal one was significantly better than signals four, five, six and eight.

I am in automated mode

Results suggested that signal design two (slow-pulsing light band) emerged as the clear preference for conveying the message that the vehicle was in automated mode. Paired contrasts confirmed that signal two was significantly better than signals three, seven, eight, nine and ten. There was little differentiation between other signals, although there appeared to be a particular lack of preference for auditory signals, as the two signals using only this mode (eight and nine) had two of the three lowest worth estimates. Signal eight was significantly worse than 7 of the other 9 signals, whilst signal nine was significantly worse than 6 of the other 9 signals.

I will start moving

Results suggested a very strong preference for signal design ten (multi-modality) as best conveying that the vehicle was about to start moving. This was the 'winning' signal by a large margin, with paired contrasts confirming it was significantly better than all other signals apart from signal one (fast-pulsing light band). Signal one was significantly better than 6 of the other 9 signals, but there was little to differentiate between the remaining signal designs.

Task 2

In this task, participants rated to what extent each eHMI signal design conveyed one of the three messages. A higher rating indicated greater agreement that the signal conveyed the message.

'I am giving way'

Table 2 provides the mean and S.D. of each signal design for conveying the message "I am giving way".

A linear mixed-effect model suggested no significant differences between the ten signal designs ($F(119) = 0.18$, $p = .667$). However, an examination of the means suggests that the most preferred options for this message are signal one (fast-pulsing light band ($M = 4.58$, $S.D. = 1.73$), signal ten (multi-modality - fast pulsing light band and fast auditory signal, $M = 4.57$, $S.D. = 1.65$), and signal seven (conventional flashing headlights, $M = 4.18$, $S.D. = 1.99$). On the other hand, the least preferred eHMI signal design was signal six (slow pulsing single lamp; $M = 2.24$, $S.D. = 1.64$).

Signal Design No.	Data Available (N)	Mean	S.D.
1	12	4.58	1.73
2	14	3.93	1.21
3	13	2.69	1.49
4	16	2.75	1.06
5	15	2.80	1.66
6	17	2.24	1.64
7	11	4.18	1.99
8	14	3.79	1.31
9	14	2.43	1.50
10	14	4.57	1.65

Table 2: To what extent each eHMI signal design conveys 'I am giving way' (Mean and S.D.)

'I am in automated mode'

Table 3 provides the mean and S.D. of each signal design for conveying the message "I am in automated mode".

Signal Design No.	Data Available (N)	Mean	S.D.	Pairwise significant differences
1	15	4.20	1.21	A
2	12	5.33	0.89	B
3	15	4.13	1.73	C
4	12	4.08	1.31	D
5	17	4.12	1.41	E
6	13	5.00	1.22	F
7	11	1.82	1.33	A,B,C,D,E,F
8	13	2.92	1.66	A,B,C,D,E,F
9	16	2.19	0.98	B,F
10	13	3.08	1.93	B,F

Table 3. To what extent each eHMI signal design conveys 'I am in automated mode' (Mean and S.D.). Signals with same letter had significantly different ratings (p < .05).

A linear-mixed effect model confirmed significant differences between ratings of the signal designs ($F(115) = 31.1$, $p < .001$). Pairwise significant differences were assessed using Tukey's all-pair comparisons and are shown in Table 3. According to the results, the Top 3 eHMI signal designs which best convey the signal message 'I am in automated mode' are signal two (slow pulsing light band; $M = 5.33$, $S.D. = 0.89$), signal six (slow pulsing single lamp; $M = 5.00$, $S.D. = 1.22$), and signal one (fast-pulsing light band, $M = 4.20$, S.D. = 1.21). The least preferred eHMI signal design for this message was signal seven (flashing headlights; M = 1.81, $S.D.$ = 1.33), which was received significantly lower ratings for this message than any of the top three options.

'I will start moving'

Table 4 provides the mean and S.D. of each signal design for conveying the message 'I will start moving'.

Signal Design No.	Data Available (N)	Mean	S.D.	Pairwise significant differences
1	12	4.25	1.28	A
2	15	3.33	1.50	B,C
3	11	3.18	1.47	D
4	15	3.60	1.59	E,F
5	16	3.00	1.63	G
6	11	1.82	0.75	A,B,E,H,I,J
7	18	3.39	1.97	H,K
8	12	4.40	1.55	L,M
9	15	2.50	1.62	J,L
10	16	5.38	1.09	C,D,F,G,I,K, M

Table 4. To what extent each eHMI signal design conveys 'I will start moving ' (Mean and S.D.). Signals with same letter had significantly different ratings (p < .05).

A linear-mixed effect model confirmed significant differences between ratings of some of the signal designs ($F(120) = 4.81$, $p = .030$). Pairwise significant differences were assessed using Tukey's all-pair comparisons and are shown in Table 4. According to the results, the Top 3 eHMI signal designs for conveying that the vehicle is about to start moving are signal ten (multi-modality; M = 5.38, $S.D.$ = 1.09), signal eight (fast auditory cue; M = 4.40, $S.D.$ = 1.55), and signal one (fast pulsing light band; M = 4.25, $S.D.$ = 1.29). The least preferred eHMI signal design for this message was signal six (slow pulsing single lamp; M = 1.82, $S.D.$ = 0.75), which received significantly lower ratings than signal ten and signal one.

DISCUSSION

The aim of this study was to investigate which eHMI signal designs were better matched to each of the following three messages: 'I am giving way', 'I am in automated mode' and 'I will start moving'. In order to provide a deeper understanding of whether participants' choices were consistent, we used two different methods to investigate the same research question. Task 1 adopted a paired-comparison forced choice method, which provided a ranking of which eHMI signal designs was the best match for each signal message. Task 2 investigated the extent to which each of these eHMI signal designs conveyed the intended signal message. Findings from both Task 1 and Task 2 show some consistency in how people interpreted the different signal designs that were presented.

Overall, the findings seem to suggest that participants were more inclined to choose, and to provide higher ratings for eHMI signal designs which were presented in a 360° Light Band form as compared to a Single Lamp. The Light Band is visible from many different angles, and can also be seen from further distances as it covers a greater surface area of the vehicle. This greater visibility may provide an advantage in real-world circumstances where other road users are approaching the vehicle from different directions. This finding may also provide some explanation for the contradictory results obtained by Habibovic et al. [14] and Ackermann et al. [2]. Habibovic et al. [14] used a light band at the top of the windscreen to convey intent, while Ackermann et al. [2] used a single light bulb, which may have been more difficult for participants to see, and therefore, to interpret.

Participants were also more inclined to choose, and provide higher ratings for eHMI signal designs which incorporated pulsing lights, rather than animations where the light filled from front to back or from back to front. This may have been caused by the fact that it took a longer time to view the complete band-filling animations, whereas the pulsing animations could be identified more quickly. Interestingly, Habibovic et al. [14] found that, with training, participants could correctly interpret band-filling animations on the top of a windscreen, suggesting that these types of animations may be more successful if presented over a smaller interface. The use of pulsing lights and sounds conforms to existing vehicle communication tools, which may have led to greater participant comfort with these signals [24]. The fact that the use of flashing headlights was also highly rated, at least in terms of conveying the message that the AV was giving way, provides support for the importance of familiarity in the interpretation of signals.

Participants also provided high ratings and ranking for multiple modality and auditory cues, particularly for conveying that the AV was about to start moving.

Conveying Specific AV messages

Out of the ten eHMI signal designs investigated, the two clearly preferred designs for conveying the message 'I am in automated mode' were the Slow Pulsing Light Band and the Slow Pulsing Single Lamp. Auditory and mixed-modality eHMI signals received poor ratings for conveying this message. These results suggest that road users do not want to be bombarded with constantly changing light and sound patterns when no change of either vehicle or other road user behaviour is required.

The three most preferred eHMI signal designs for conveying the AV message 'I am giving way', were the Fast Pulsing Light Band, Multiple Modality (Fast Pulsing Light Band and Fast Auditory cue) and conventional Flashing Headlights. In current vehicle-pedestrian and vehicle-vehicle interactions, drivers often use flashing headlights to inform pedestrians that they are yielding [9], and it would still be possible to use this type of signal during automated driving. However, it is interesting to note that the newly designed Fast Pulsing Light Band and Multiple Modality were interpreted equally well as headlight flashing. As there has been some argument about the importance of ensuring that other road users are able to differentiate AVs from other vehicles on the road [10], the use of these new signals may provide an alternative form of communicating when an AV wishes to yield to another road user.

Across the two tasks, there was one eHMI signal design that stood out from others in conveying 'I will start moving'. This was the Multiple Modality combination of Fast Pulsing Light Band and Fast Auditory Cue. The next two most highly rated signals were Fast Auditory Cue and Fast Pulsing Light Band. It seems that the use of rapidly changing eHMI provides a warning indication of 'be aware' or 'warning', which would effectively draw the attention of other road users to the change in the AVs status from safe (static) to less safe (moving), in a similar manner to the use of the conventional honking sound in today's traffic environment [8, 17]. The use of auditory cues is supported by the research by Mahadevan et al. [23] who found that a small majority of participants (6 out of 10), in their proof-of-concept study, expressed a liking for audio feedback from the vehicle for awareness communication. However, it may be difficult for pedestrians to pick up on these sounds in busy traffic environments.

Interestingly, the Fast Pulsing Light Band and Multiple Modality appeared as the best-rated signals for two different messages, 'I am giving way' and 'I will start moving'. These two messages reflect contradictory behaviours of the vehicle. For instance, vehicles which are giving way are more likely to decelerate and/or stop, potentially increasing the safety of the other road user, whereas vehicles that start moving are indicating an intention to start accelerating, thus leading to a potential decrease in road user safety. This finding suggests that the use of these rapidly changing eHMI concepts is more likely to suggest a general AV behavioural change. Therefore, the fast pulsing light band and auditory cues might have been interpreted as 'Be aware', or 'I am about to change my behaviour' This finding is supported by the fact that the fast pulsing light band and multiple modality led to the fastest responses by participants, who often made their decision without waiting for the whole animation to be completed. In addition, the interpretation of the Fast Pulsing Light Band signal may be context specific, similar to when headlights are flashed. For example, if you are arriving at a junction and see a flashing headlight from a fast moving vehicle, the flashing headlights may be interpreted as 'Do not step out / pull out in front of me'. However, if you observed a vehicle which was decelerating and flashing its headlights, it may be interpreted as 'I am yielding' [9].

CONCLUSIONS & FUTURE RESEARCH

This study demonstrated that the same eHMI signal design can be interpreted in different ways, and can be used to convey different messages equally well. It is possible that a simple communication of a change in AV behaviour is enough to draw other road users' attention and caution, without the eHMI having to specify what changes is. However, it is very important that the use of one eHMI design does not result in misinterpretation which could lead to dangerous behaviours on the part of other road users, for example, through a false sense of safety. Future research should investigate whether incorporating exaggerated vehicle movements would help VRUs more clearly understand the use of eHMI signals in different contexts.

Finally, this study has investigated the comprehension of the eHMI signal designs without providing any context, and this might cause different interpretations to occur in the real world. Recent studies by Habibovic et al. [14] and Mahadevan et al. [23] have found that light-based signals can be correctly interpreted during interactions with AV-like vehicles, providing some reassurance that the current results can be applied in real-world settings. One of the strengths of the methodology used in this study is that it provides a relatively fast and cost-effective means of discriminating between the usefulness and acceptance of different signal designs. Thus, the ranking process provides a method which can be used to select appropriate designs to take to the next stage of development, where more ecologically valid testing is crucial. The combination of both eHMI signal design and the behaviour/movement of the vehicle is very important in determining the vehicles' intention [16, 19, 28], and needs to be taken into account when determining how these signals are interpreted in real-world settings. Future studies should investigate which eHMI signal designs are more efficient in helping pedestrians to make safe crossing judgments, along with further exploring the learnability of the eHMI signal designs [20].

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