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What externally presented information do VRUs require when interacting with fully Automated Road Transport Systems in shared space?

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ABSTRACT

As the desire for deploying automated (“driverless”) vehicles increases, there is a need to understand how they might communicate with other road users in a mixed traffic, urban, setting. In the absence of an active and responsible human controller in the driving seat, who might currently communicate with other road users in uncertain/conflicting situations, in the future, understanding a driverless car’s behaviour and intentions will need to be relayed via easily comprehensible, intuitive and universally intelligible means, perhaps presented externally via new vehicle interfaces. This paper reports on the results of a questionnaire-based study, delivered to 664 participants, recruited during live demonstrations of an Automated Road Transport Systems (ARTS; SAE Level 4), in three European cities. The questionnaire sought the views of pedestrians and cyclists, focussing on whether respondents felt safe interacting with ARTS in shared space, and also what externally presented travel behaviour information from the ARTS was important to them. Results showed that most pedestrians felt safer when the ARTS were travelling in designated lanes, rather than in shared space, and the majority believed they had priority over the ARTS, in the absence of such infrastructure. Regardless of lane demarcations, all respondents highlighted the importance of receiving some communication information about the behaviour of the ARTS, with acknowledgement of their detection by the vehicle being the most important message. There were no clear patterns across the respondents, regarding preference of modality for these external messages, with cultural and infrastructural differences thought to govern responses. Generally, however, conventional signals (lights and beeps) were preferred to text-based messages and spoken words. The results suggest that until these driverless vehicles are able to provide universally comprehensible externally presented information or messages during interaction with other road users, they are likely to contribute to confusing and conflicting interactions between these actors, especially in a shared space setting, which may, therefore, reduce efficient traffic flow.

1. Introduction

There is no doubt that the private motor vehicle and our transport system are currently undergoing their biggest facelift, in terms of both functionality and use, since the first fleet of vehicles was manufactured by Henry Ford in the early 20th century. Thanks to the addition of a plethora of Advanced Driver Assistance Systems (ADAS), an increase in seatbelt use, the inclusion of passive safety features such as airbags, and the production of more robust vehicle bodies, the number of fatalities from motor vehicle crashes is falling on an annual basis (OECD et al., 2013), and today’s private passenger cars are a relatively safe mode of transport.

Utilisation of the private automobile has also evolved in recent times with a number of surveys suggesting that, for example, in the developed world, Millennials (those aged 18 – 24 years) are not particularly interested in owning a car, and many do not even have a driver’s licence (Time Magazine, 2013). It is currently unclear whether this change in car ownership is because this demographic prefers to spend its time and resources on other devices and technology such as mobile phones, or simply because owning and maintaining a car is considered expensive and a luxury (Delbosc and Currie, 2013). A factor that is likely to contribute to this finding is the provision of other forms of transport, including better public transport networks, accessible in many European cities, or the availability of car sharing/pooling facilities; improved walking and cycling provisions; and the development and readiness of new on-demand personal transport options, such as Uber.

One additional form of public transport, which is not yet in mass production, but likely to be deployed on our roads in the future, is a form of fully automated low speed vehicle or “driverless” vehicle,

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which has recently attracted the interest of some city authorities in Europe, North America, and Singapore. Taking a number of forms, and providing space for between 1 and 12 passengers, the functionality, purpose and service provided by such forms of transport is fundamentally different from that of privately owned automated vehicles being developed by most automotive manufacturers. Thus far, these SAE Level 4 vehicles (Society of Automotive Engineers SAE, 2016) have been manufactured for use in urban settings, sometimes in shared space with other road users. In Europe, the first of such vehicles was developed by projects such as CyberCars and CyberMove (see Parent and de La Fortelle, 2005). As outlined at a recent symposium organised by the National Academy of Sciences (TRB, 2015), this type of driverless car normally travel at low speeds, up to around 25 mph, in urban settings, and is typically electrically powered. Navigation is via a combination of Simultaneous Localisation and Mapping (SLAM) and LIDAR, and many forms of such vehicles do not normally contain a steering wheel or other typical driving-based controls. Safe and timely obstacle/pedestrian detection is generally achieved via sensors and radars (Urmson et al., 2008) and a trained human operator is present in the vehicle to manage any unexpected failures or incidents. Currently, these vehicles are mostly used and implemented for research and demonstration purposes, but ultimately, there is a desire to use them for revolutionising urban mobility, by reducing the impact of transport on the environment, increasing safety, and enhancing movement and accessibility for a currently excluded group of users, such as the disabled and older drivers (Alessandrini et al., 2015). Operating in harmony with other forms of public transport, such vehicles are considered a good example of first mile/last mile transport solutions, which enable users to travel from their homes to/from public transport hubs.

In Europe, a number of projects have considered the feasibility of such systems, including the CityMobil2 project funded by the European Commission (see Alessandrini et al., 2015), the GateWay project, funded by the UK Government (GateWay, 2016), and the Dutch WePods Project (see WePods, 2016). In each case, the research has mainly focused on technological improvements, such as ensuring the successful functionality of radars and sensors, confirming correct navigation on a designated route, and ensuring that the vehicles can handle sudden and unexpected changes in weather and environmental conditions. In terms of user involvement, passengers' or users' opinions of the functionality, comfort, value for money, etc. of the vehicle is normally sought (see Stam et al., 2015), with less emphasis on how such driverless vehicles will eventually interact and communicate with other road users, such as drivers of manually driven vehicles, or Vulnerable Road Users (VRUs) such as pedestrians and cyclists.

It can be argued that in the absence of a driver, or dedicated traffic signals and infrastructure, there is clearly a need for some form of communication framework to be established between all actors interacting with a driverless vehicle. This is especially important if VRUs can no longer see an obvious controller of the vehicle (driver) and are unable to rely on non-verbal means of human communication (such as eye contact or head and hand movements).

Using specially adapted 'driverless' vehicles, the importance of these issues is highlighted by two recent studies reporting on the opinion and behaviour of pedestrians interacting with such vehicles during field/observation studies. Here, the driver of a real passenger car is either 'fake', by adding a steering wheel on the vehicle's passenger side (where the passenger is perceived as the driver), or hidden behind an adapted seat (Habibovic et al., 2016; Rothenbucher et al., 2015, respectively). Interesting insights are provided by these studies, suggesting feelings of unease by pedestrians who see the fake driver distracted or asleep behind the wheel of a 'driverless' car (Habibovic et al., 2016), and confirming that after some training, pedestrians are able to identify a set of messages portrayed by the vehicle, using a set of specially designed, externally placed, moving lights (Habibovic et al., 2016). Examples of messages included information about whether or not the vehicle was functioning in automated mode, and whether it was intending to move after approaching a crossing. One challenge, of course, is that there is currently little knowledge regarding the best mode and nature of these types of communication, such as the most suitable colour, direction of movement and position of externally presented lights. Ensuring that these messages are understood globally by road users is also a key challenge for OEMs in this area.

The value of some form of communication, which will replace messages normally relayed by human drivers, has also been acknowledged recently by a number of vehicle manufacturers, and others working in this area. For instance, Google has filed a patent illustrating a set of texts and images which provide advice for pedestrians about whether or not it is safe to cross in front of the vehicle (Urmson et al., 2015). However, a study conducted by researchers at Duke University suggests that most pedestrians use implicit cues from the vehicle, such as estimating its approaching speed when crossing an un-signalised section of road, rather than looking at explicit messages displayed on the outside of the vehicle (Clamann et al., 2017). Clamann et al., (2017) also found the visibility of such images to be problematic for pedestrians, who were unable to decipher the symbols from far away.

It can be argued that as the testing and deployment of driverless cars become more commonplace, VRUs may feel reassured that the obstacle detection features of these vehicles will ensure collision avoidance. However, the lack of an appropriate form of external communication by these driverless vehicles has provided a number of anecdotal observations which illustrate a form of "standstill" between them and VRUs, especially because the vehicle cannot currently change its path if it is confronted by an obstacle. If the VRU does not alter their position to stop blocking the vehicle, the two actors will remain in a standstill, until one backs down or the human operator has to resolve the conflict by intervening, as has occurred, for example, between a Google car and cyclist (Roadbike Review, 2015) and during the CityMobil2 demonstrations on the busy seaside promenade of Sardinia.

This lack of conventional communication between VRUs and vehicles is likely to lead to frustrations for the VRUs, increasing the degree of conflict and creating awkward interactions. If humans form an incorrect mental model of the ARTS' trajectory and intentions, this may even reduce VRU safety. The fact that engine noise is almost completely absent in these electrically powered vehicles may exacerbate the problem in a multi-actor traffic environment, where the approach of the ARTS may not be heard.

Therefore, while the safety features of an automated vehicle do indeed prevent it from colliding with a VRU, such frustrating and awkward scenarios can only be resolved if the human and the machine are able to communicate their intentions to one another effectively. The challenge for vehicle manufacturers is, therefore, to identify the type of information required by VRUs in such circumstances, in order to design and implement the most suitable Human Machine Interfaces (HMI) for providing external communication by the vehicle. Knowledge on whether this communication should match conventional forms of interaction observed between VRUs and drivers of normal vehicles is limited, and it is not clear whether other forms of communication language are needed, or likely to evolve with further deployment of these vehicles. For instance, a number of vehicle manufacturers are currently considering how natural human gestures can be used to train the automated vehicle to understand the intention and behaviour of the VRUs (e.g. see SafeCar News, 2014).

Therefore, as a first step towards addressing this need, the aim of this exploratory study, conducted as part of the CityMobil2 European project, was to investigate what information VRUs might require about the ARTS' movement intentions, and also the means and mode by which they wished to receive this information. Participants were also asked to comment on their feeling of safety during the ARTS demonstrations and state whether, and when, they believed they had priority of movement over the ARTS. Recently, Human Factors research and development in this area has focussed heavily on understanding the challenges drivers inside the car face when interacting with an automated vehicle (see

Merat and Lee, 2012 for an overview). However, perhaps partly due to the absence of genuine demonstrators of fully automated ARTS, there is little understanding of the interactions between VRUs and ARTS in real-world, or even experimental settings, apart from those cited above. In designing this study, we hoped that any insight on this topic would help system developers when considering the type, position and level of externally presented information for such ARTS. A crucial aspect of the data reported here is that it was collected at the time of the VRU's actual interaction with ARTS during demonstrations in three European cities, starting from the first such demonstration in La Rochelle, in 2014. This was done because it is important to gain an understanding of requirements from people who have actually experienced interacting with a system, as previous studies have shown that ratings of the acceptability of a system prior to use are not necessarily linked to actual acceptance of these systems after implementation (Schuitema et al., 2010). In addition, it was important for the users to be aware of the capabilities and limitations of the actual vehicles under investigation for this study.

2. Method

Individual demonstrations of the ARTS vehicles took place in La Rochelle, France, Lausanne in Switzerland and Trikala in Greece, between November 2014 and February 2016 (Fig. 1). A 42-item questionnaire was administered to cyclists and pedestrians who shared the same space as the vehicles during the live demonstrations and confirmed using the ARTS to travel as a passenger at least once. As only some items from this questionnaire were relevant to the external messages presented by the ARTS, only a sub-section of results from the full questionnaire are presented in this paper (see below).

Fig. 1. CityMobil2 vehicle in Trikala (TOP), Lausanne (MIDDLE) and La Rochelle (BOTTOM).

The questionnaire was developed in English and then translated into French and Greek by French and Greek-speaking project partners located in the demonstration cities. Before final administration, each translation was then re-checked by an independent French or Greek-speaking colleague at Leeds. Ethical consent for the study was obtained from the University of Leeds Ethics Committee (Ref: LTTRAN-040).

For the La Rochelle demonstration, the 2.6 km route for ARTS was integrated into the main city road network, and included areas of interaction with other road users (Graindorge, 2016). The Trikala route was also implemented in the city centre, but used a dedicated lane, previously used for busses. New traffic signals were developed to assist with mixed traffic interactions for both La Rochelle and Trikala participants. The Lausanne demonstration took place in a simpler setting of the École Polytechnique Fédérale de Lausanne (EPFL) campus, containing mostly pedestrianised areas with less vehicular traffic, but still including opportunities for interaction with other road users.

Development of the questionnaire was informed by a series of one to one interviews with 26 participants from Leeds, UK and Braunschweig in Germany (see Schieben et al., 2018 submitted), which were designed to explore interviewee's perceptions of, and attitudes towards, automated road vehicles, along with their communication preferences for these vehicles (Merat et al., 2016).

For the live demonstrations, although it was important to ensure that respondents had used the ARTS, so that they were aware of its limitations and capabilities, the questions reported here were specifically developed to seek their views as pedestrians and cyclists, interacting with the vehicles in shared space. Some of the items on the questionnaire focused on users' behavioural intention to use the ARTS (see Madigan et al., 2016, 2017), while the remainder focused on participants' opinions as VRUs. This paper, therefore, reports only on a selection of the 42-item questionnaire (questions 9–13 and 16 to 22 – see Appendix. For the full set of questions see Merat et al., 2016).

2.1. Participants

Six hundred and sixty-four participants were recruited across the three sites, and attention was given to ensuring a representative sample of ages and gender for each site, as outlined in Table 1.

2.2. Questionnaire items

2.2.1. Safety and priority in shared space

Questions 9–11 (see Appendix A in Supplementry material) were designed to seek respondents' views on how they would navigate

Table 1
Demographic information from the three sites.

		La Rochelle (N = 204)	Lausanne (N = 145)	Trikala (N = 315)	Total
Gender	Male	59.8%	64.1%	54.6%	58.30%
	Female	40.2%	35.9%	45.4%	41.70%
Age (years)	< 16	0%	0%	5.4%	2.6%
	16–17	1.0%	0%	3.2%	1.8%
	18–24	36.8%	52.4%	13.3%	29.1%
	25–34	11.8%	23.4%	33.7%	24.7%
	35–44	11.8%	13.8%	33.7%	22.6%
	45–54	12.7%	4.1%	7.0%	8.1%
	55–64	12.3%	5.5%	2.9%	6.3%
	65–74	11.3%	0.7%	1.0%	4.1%
	> 74	2.5%	0%	0%	0.8%

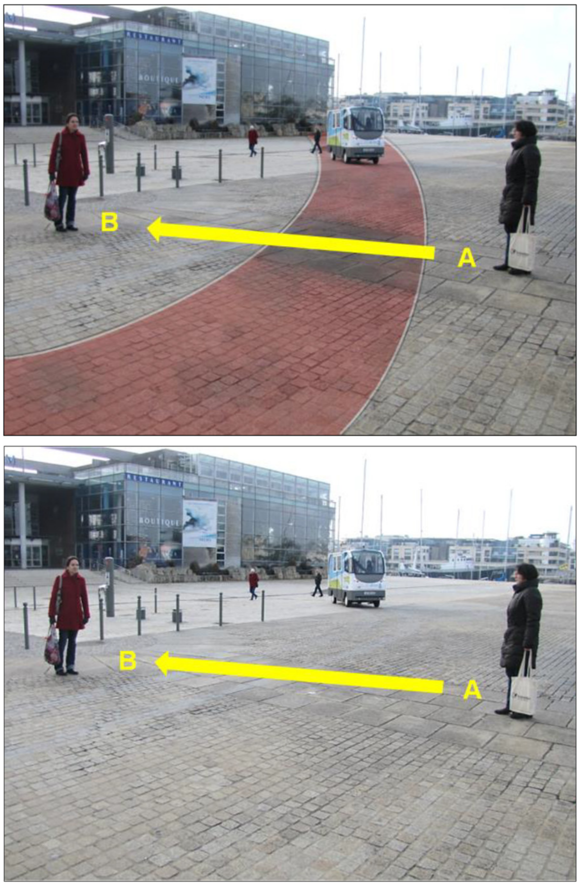

Fig. 2. Photographs showing the interaction of pedestrians with the ARTS in dedicated (TOP) and shared (BOTTOM) space.

Fig. 3. Data collection in La Rochelle, France.

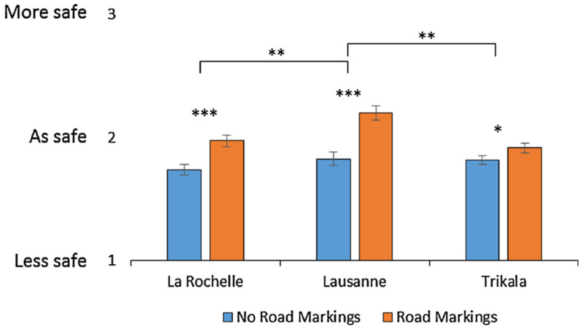

Fig. 4. Participants' feeling of safety towards the ARTS, when asked to compare to a manually driven vehicle. ($^{***}p < .0001$, $^{**}p < .001$, $^{*}p < .05$). (Error bars represent S.E).

around the infrastructure used for the ARTS demonstrations. As shown in Fig. 2, respondents were shown two photographs which depicted a potential interaction scenario between road users and vehicles. The aim of these photographs, which were presented in a counter-balanced order across participants from the three sites, was to determine respondents' views on safety and priority during interactions with ARTS, comparing a shared versus dedicated environment, and assessing differences between ARTS and manually driven vehicles. Taken from parts of the route in La Rochelle, which did not contain any road markings, the photographs were edited to include suitable road markings. The same photographs were used in all three cities.

2.3. *Type and mode of communication*

Following the above questions, participants were asked to rate the importance of certain vehicle manoeuvres and travel behaviour (see Q12. in Appendix A in Supplementry material), and then asked to indicate how they wanted this information to be presented (using a choice of modalities – see Q13. Appendix A in Supplementry material). These questions were partly informed by the interviews conducted in Leeds and Braunschweig, and used to determine the importance and nature of externally presented messages.

Finally, to understand whether results were influenced by participants' overall preferences for intelligent systems and new technologies, their response to the following statement was recorded: "*When it comes to trying a new technology product, I am generally*: a) among the last, b) in the middle, c) among the first.

2.4. *Administration of the questionnaire*

After the questionnaire was developed at Leeds, and translated as described above, responsibility for data collection was assumed by local representative partners from L'Ecole d'Ingénieurs en Génie des Systémes Industriels (EIGSI) in La Rochelle, École Polytechnique Fédérale de Lausanne (EPFL) in Lausanne, and the Institute of Communications and Computer Systems (ICCS) and E-Trikala, in Trikala. Data collection was achieved via a Personal Digital Assistant in La Rochelle and Trikala (see Fig. 3) and using an on-line system in Lausanne. Questionnaires were largely self-administered, apart from a few cases where respondents had difficulties operating the tablets, in which case the project team captured responses. Participants were not compensated for their time to respond the questionnaires, which took around 10–15 min to complete.

2.5. *Statistical analysis*

The questionnaire data was analysed using a variety of parametric and non-parametric techniques. Analysis of Co-Variance (ANCOVA) was used to evaluate participants' perception of safety, and the importance of information on various ARTS behaviours. Age and gender

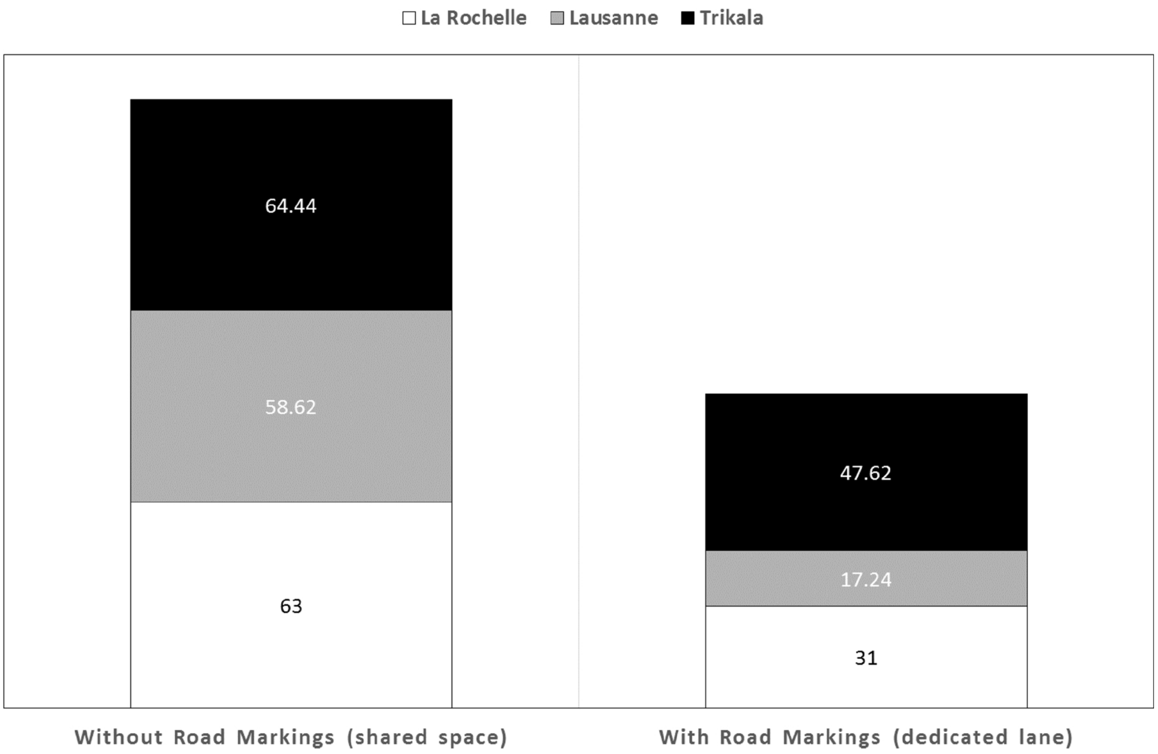

Fig. 5. Participants' judgement of priority over the ARTS during dedicated and shared space settings (numbers represent % of participants in each city).

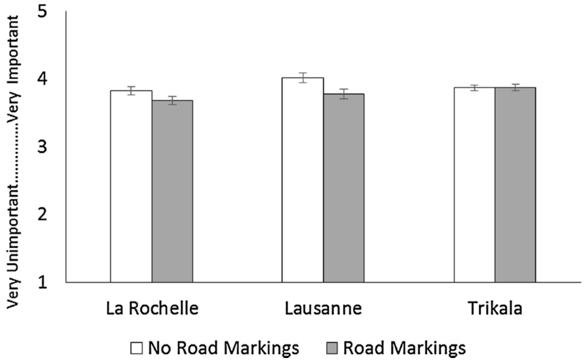

Fig. 6. Importance of information received from the ARTS for each location (Error bars represent SEM).

were included as covariates, as previous studies have suggested that there may be age and gender differences regarding the use and acceptance of such technologies, as originally proposed by the Technology Acceptance Model (Davis, 1989; Venkatesh, 2000). For the categorical data, both McNemar's test and Cochran's Q test were used to evaluate differences in feelings of priority, and differences in preferred communication modality, in the presence and absence of road markings. The McNemar's test is used to determine if there are differences on a dichotomous dependent variable between two related groups. It is similar to the paired sample t-test, but for a dichotomous rather than a continuous dependent variable (Laerd, 2015). The Cochran's Q test can be considered an extension of the McNemar's test, used to determine differences on a dichotomous dependent variable for three or more related groups (Laerd, 2015). Finally, Chi-Squared analyses were used to determine any differences in response to categorical variables across the three locations.

3. Results and discussion

Results showed that 82% of participants had interacted with the ARTS between 1 and 5 times, before responding to the questionnaire. The group was well-balanced in terms of their willingness to use new technologies, with nearly 30% of respondents considering themselves as being "among the last", while almost 54% said they were "in the middle", and just under 17% reported they were "among the first" to test and experience new technologies. La Rochelle respondents were the most technology savvy, with nearly 21% of respondents in this location reporting that they were generally "among the first" to try new technologies.

Using the photographs in Fig. 2, participants were asked to rate their perception of safety during interaction with the ARTS, when compared to a manually driven vehicle (Q11). A mixed 2 × 3, repeated-measures Analysis of Co-Variance (ANCOVA) was conducted on the results, with Road Markings (without road markings, with road markings) as a within-subjects factor, Location (La Rochelle, Lausanne, Trikala) as a between-subjects factor, and Gender (male, female) and Age

Table 2
t-tests evaluating the effect of road markings on ratings of importance for all ARTS behaviours.

	Without Road Markings	With Road Markings	Effects of Road Markings
Whether it is stopping	3.99 (.039)	3.88 (.040)	**$t(663) = 3.454, p < .001$**
Whether it is turning	4.00 (.037)	3.80 (.041)	**$t(663) = 5.296, p < .001$**
How fast it is going	3.64 (.043)	3.60 (.084)	$t(663) = 1.152, p = .250$
Whether it is going to start moving	3.88 (.040)	3.84 (.040)	$t(663) = 1.399, p = .162$
Whether it has detected me	3.93 (.042)	3.87 (.042)	$t(663) = 1.913, p = .056$

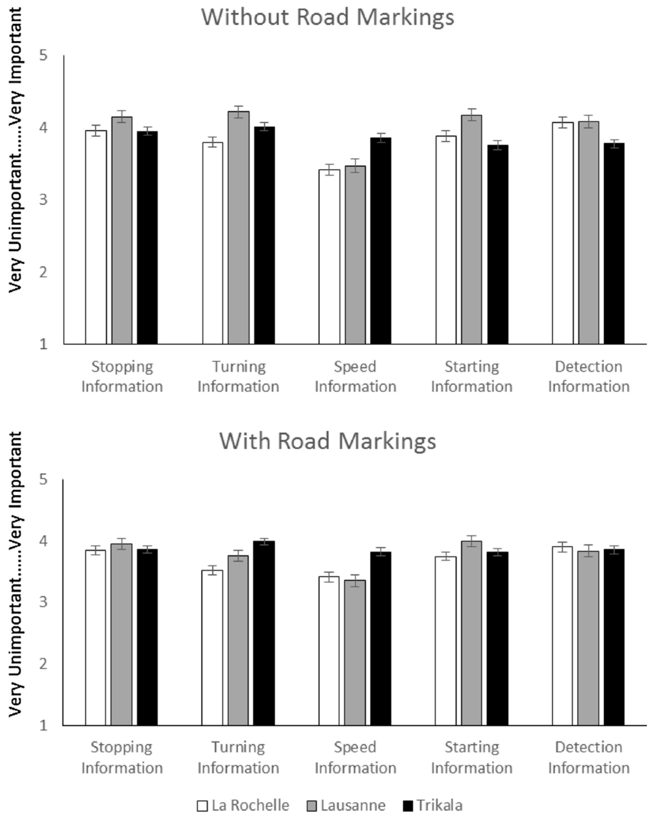

Fig. 7. Importance of information received for each ARTS behaviour across locations, with and without road markings (error bars represent SEM).

(16–24, 25–44, < 45) as co-variates. Post-hoc LSD comparisons were used, where significant main and interaction effects were observed.

Results showed a significant effect of Road Markings ($F(1,659) = 5.27$, $p < .05$, $\eta_p^2 = .08$), with overall lower perceptions of safety in the shared space environment without Road Markings ($M = 1.80$, $SEM = .03$ vs $M = 2.03$, $SEM = .03$, respectively). There was also a significant effect of Location ($F(2,659) = 4.66$, $p < .01$, $\eta_p^2 = .01$) and post-hoc LSD comparisons showed that participants in Lausanne generally felt the safest around the ARTS ($M = 2.02$, $SEM = .05$), compared to those in La Rochelle ($M = 1.86$, $SEM = .04$, $p < .005$) and Trikala ($M = 1.86$, $SEM = .03$, $p < .01$). This is perhaps not too surprising since the Lausanne demonstration was situated in and around the EPFL campus, rather than within an urban setting. The fact that the vehicle used in Lausanne was of a different appearance to those used in Trikala and La Rochelle (see Fig. 1) may also be relevant to these results. Finally, Trikala represented the most complex setting, containing a number of intersections, where VRUs had to negotiate interactions with both the ARTS and other traffic, such as manually driven cars and cyclists. This may clarify why these respondents felt least safe.

Results also showed a significant interaction between Road Markings and Location ($F(2,659) = 6.27$, $p < .01$, $\eta_p^2 = .02$), which, as shown in Fig. 4, suggests no difference across locations in feelings of safety in the absence of Road Markings, but a higher perception of safety, particularly for the Lausanne participants, with Road Markings. A series of post-hoc paired *t*-tests determined that there was a statistically significant increase in safety perception with Road Markings for respondents in La Rochelle ($t(203) = -4.43$, $p < .001$), Lausanne ($t(144) = -6.73$, $p < .001$), and Trikala ($t(314) = -2.36$, $p < .05$). There was no effect of Age or Gender.

Participants were also asked to use the photographs in Fig. 2, to judge whether they had priority in movement over the ARTS (Q10, Appendix A in Supplementry material). Exact McNemar's tests (McNemar, 1974) were conducted on the responses to assess statistical significance. Results showed that, for all three sites, a larger proportion of participants considered the ARTS to have priority in movement when a dedicated lane was present, but that this priority then transferred to them as VRUs in the shared space setting (χ^2 (1, $N = 560$) = 94.69, $p < .001$). This was particularly the case for respondents in Lausanne and La Rochelle. However, although the Trikala respondents were clear about their priority in shared space, there was less consensus about who had priority when considering the dedicated lane option (see Fig. 5).

These results provide an interesting insight, since the pedestrians and cyclists in this study were clearly expecting priority in the shared space setting, as is the general expectation from such infrastructure (Hamilton-Baillie, 2008; Kaparias et al., 2012). Therefore, if such priority is not honoured by the driverless vehicle, a conflict may arise between the different actors interacting in shared areas. Since most such demonstrations of low speed automated vehicles are currently taking place in mixed traffic settings, without demarcated lanes, where (it seems) pedestrians expect to have priority over the ARTS, some consideration is required by city planners and vehicle manufacturers to ensure a reduction of unsafe conflicts. Furthermore, since the ethos of shared space is for drivers to “engage more with their surroundings” and portray “enhanced alertness” (Adams, 1995), the challenge for manufacturers is to ensure the same standards are obeyed by driverless vehicles.

Next, participants were asked to report the importance they placed on receiving some form of communication from the vehicle (using a 5 point scale, Q12). To understand the relationship between road markings and the external communication information portrayed by the ARTS across the three locations, a mixed repeated-measures Analysis of Co-Variance (ANCOVA) was conducted, with Road Markings (*without road markings, with road markings*) and ARTS information (*whether it is stopping, whether it is turning, how fast it is going, whether it is going to start moving, whether it has detected me*) as within-subjects factors, and Location (La Rochelle, Lausanne, Trikala) as the between-subjects factor. We controlled for Gender (male, female) and Age (16–24, 25–44, > 44). Mauchly's test indicated that the assumption of sphericity had been violated for Information (χ^2 (9) = 290.87, $p < .001$) and the interaction between Information and Road Markings (χ^2 (9) = 53.34, $p < .001$), and therefore degrees of freedom were corrected using Huynd-Feldt estimates of sphericity ($\varepsilon = 0.82$ and $\varepsilon = 0.99$, respectively).

Results showed no significant effect of either Location ($F(2, 659) = 1.86$, $p = .16$), Gender ($F(1,659) = .29$, $p = .59$), or Age Categories ($F(1,659) = 1.71$, $p = .19$) on ratings of the importance placed on receiving some form of communication from the vehicle. However, there was a significant main effect of Road Markings ($F(1,659) = 4.71$, $p < .05$, $\eta_p^2 = .007$). Not surprisingly, participants reported an overall greater need to receive information from the ARTS, in the absence of Road Markings ($M = 3.90$, $SEM = .03$ vs $M = 3.78$, $SEM = .03$), verifying the importance of some form of communication from the ARTS in a shared space setting. There was also a significant interaction between Location and Road Markings ($F(2, 659) = 8.47$, $p < .001$, $\eta_p^2 = .03$). As shown in Fig. 6, although participants in Lausanne and La Rochelle felt that receiving information from the ARTS was more important when there were no Road Markings, this was not the case for the Trikala respondents.

There was also a significant effect of the type of information received from the ARTS ($F(3.25, 2163.28) = 9.32$, $p < .001$, $\eta_p^2 = .01$). Respondents rated information about whether the ARTS was stopping, turning, and starting, and its detection behaviour as being important or very important. However, information about the speed at which the ARTS was travelling at was considered less important. This is possibly because (due to safety reasons in a mixed traffic environment) the vehicles travelled at quite a slow speed (around 10 km/h), but also because this information is perhaps easiest to observe (see Clamann et al., 2017).

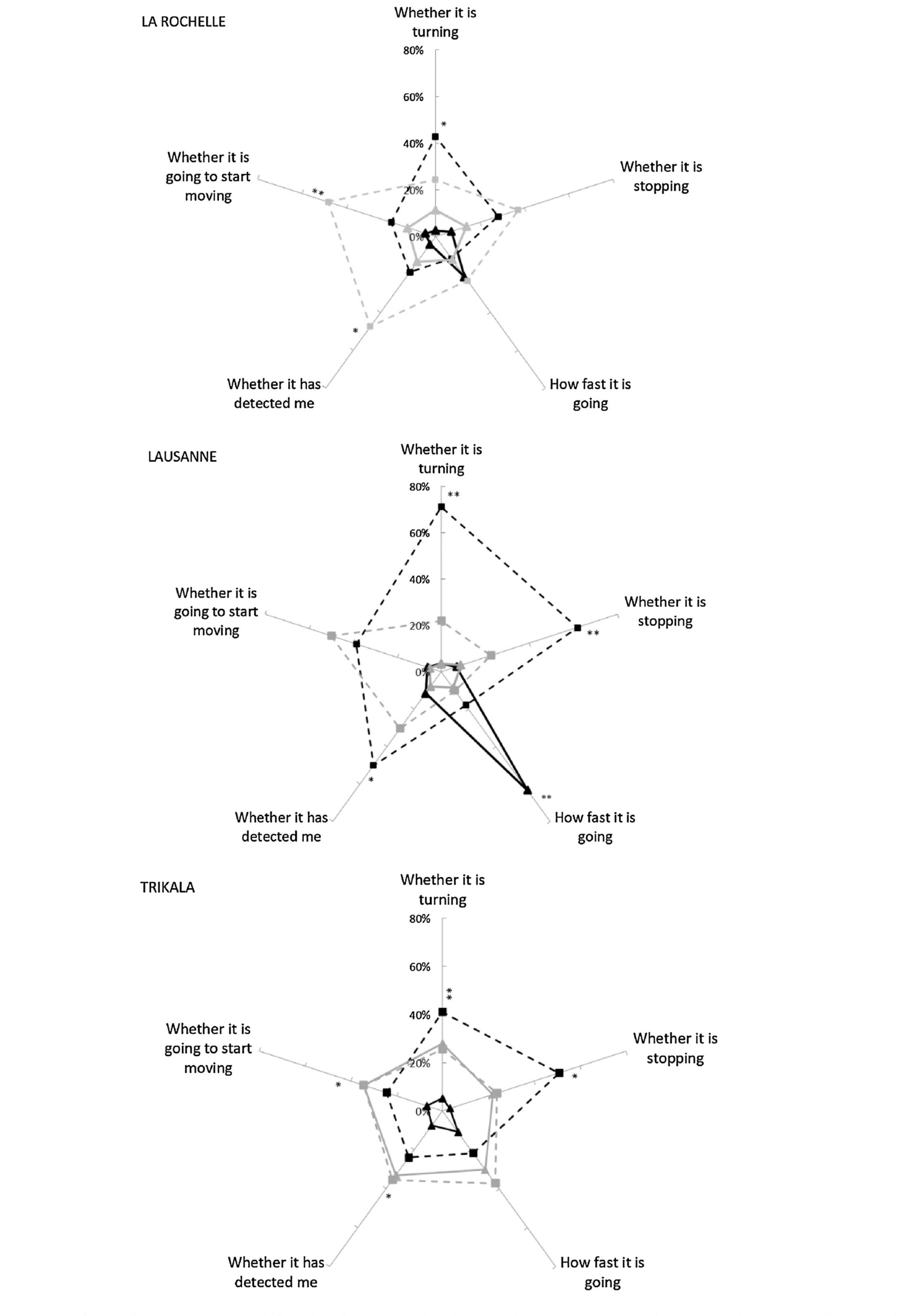

Fig. 8. Respondents' preferences for the type of signal used by the ARTS when providing information in the absence of road markings (Top: La Rochelle, Middle: Lausanne, Bottom: Trikala) $^{*}p < .05$, $^{**}p < .001$.

There was a significant interaction between Information Received and Road Markings ($F(3.89, 2568.85) = 2.87$, $p < .05$, $\eta_p^2 = .004$), with participants showing a higher preference for receiving information about stopping behaviours ($t(663) = 3.45$, $p < .001$) and turning behaviours ($t(663) = 5.29$, $p < .001$) when there were no Road Markings. There were no significant effects of Road Markings for the other behaviours of the ARTS (see Table 2).

There was also a significant interaction between Information Received and Location ($F(8, 2636) = 15.23$, $p < .001$, $\eta_p^2 = .04$), with La Rochelle respondents favouring "*whether it has detected me*" and "*whether it is turning*" as the most important messages, whilst all information was important to the Lausanne participants other than "*how fast it is going*". Trikala respondents did not show any significant preference.

Finally, there was a significant three-way interaction between Road Markings, Information Received, and Location (F (7.79, 2568.85) = 3.05, $p < .01$, $\eta_p^2 = .01$). Fig. 7shows that compared to the Trikala respondents, participants from La Rochelle and Lausanne showed less desire for receiving speed information from the ARTS, regardless of Road Markings. It is currently difficult to assess the reasons for this difference, but this finding may be linked to cultural differences in compliance with traffic rules, which have been observed between Northern and Southern European traffic participants (Golias and Karlaftis, 2001), and perhaps a need for the Trikala respondents to feel safer by receiving as much information as a possible in the complicated urban setting used for these demonstrations. Further work in this area is required to clarify these findings.

In the final section of the questionnaire, participants were asked to report what modality would be most useful for relaying the messages outlined above (see Q13, Appendix A in Supplementry material). For ease of understanding, only the main differences are reported.

A series of exact McNemar's tests, with continuity corrections (Edwards, 1948) failed to show an effect of Road Markings on participants' preferences for the modality of messages, and so the following results apply to both types of environment (with and without Road Markings). A series of Cochran's Q tests, performed to assess participants' preference for the use of a particular modality when receiving information about the behaviour of ARTS (see Fig. 8), showed that there were differences in the preferred modality across locations and only some agreement across respondents regarding the best modality for each type of message.

Cochran's Q tests suggest that La Rochelle participants only preferred visual lights to auditory signals when the ARTS wished to indicate a turn (χ^2 (1, $N = 184$) = 9.32, $p < .05$), whereas auditory signals were preferred to lights for clarifying that participants had been detected by the ARTS (χ^2 (1, $N = 181$) = 22.53, $p < .001$) and also to indicate that the vehicle was starting to move (χ^2 (1, $N = 176$) = 20.83, $p < .001$).

Respondents in Lausanne had a generally higher preference for visual lights over auditory signals, especially if they wished to know whether the ARTS was stopping (χ^2 (1, $N = 102$) = 18.61, $p < .001$), turning (χ^2 (1, $N = 118$) = 30.58, $p < .001$) and detecting them (χ^2 (1, $N = 112$) = 5.39, $p < .05$). On the other hand, this group preferred text information for knowing the speed of the vehicle (χ^2 (1, $N = 128$) = 32.35, $p < .001$).

Finally, Trikala residents were the only group who equated signals and spoken word when rating auditory messages. Overall, Trikala respondents preferred turning (χ^2 (1, $N = 315$) = 29.75, $p < .001$) to be signified by visual, rather than auditory signals, and stopping to be signified by visual, rather than spoken word (χ^2 (1, $N = 315$) = 6.95, $p < .05$). However, auditory signals were preferred over visual lights for notification of detection (χ^2 (1, $N = 315$) = 4.11, $p < .05$) and whether the ARTS was going to start moving (χ^2 (1, $N = 315$) = 5.64, $p < .05$), respectively.

4. Summary and conclusions

This study was designed to investigate the requirements of over 660 pedestrians and cyclists when interacting in the same shared space with low-speed Automated Road Transport Systems (ARTS). Questionnaires were administered to participants during live demonstrations of these 'driverless' vehicles in three European cities. Results from all demonstrations confirmed that the shared space ethos expected from manually driven vehicles was extended to these driverless cars, with participants expecting priority over the vehicles in the absence of dedicated lane markings. Lower feelings of safety were also reported when interacting with the ARTS in the absence of lane markings, and there was unequivocal agreement across the three sites that there should be some form of external communication protocol from the ARTS. Although the speed of travel of the ARTS was not considered a concern, possibly since it was low and also easy to ascertain, participants stated that they wished to receive information about the vehicle's other actions, such as whether it was turning or stopping, and whether they had been detected. There was no clear agreement across the sites for the preferred modality used to supply this information. In line with other recent studies in this field (Habibovic et al., 2016), this study confirms that until a clear external communication and interaction strategy is in place for driverless vehicles interacting with others in shared space, there is likely to be a chance of conflicts and frustrations between such driverless vehicles and VRUs.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.aap.2018.03.018.

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