Road user interactions in a shared space setting: Priority and communication in a UK car park

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Abstract

Appropriate communication between road users can lead to safe and efficient interactions in mixed traffic. Understanding how road users communicate can support the development of effective communication methods for automated vehicles. We carried out observations of 66 pedestrian-driver and 124 driver-driver interactions in a shared space setting. Specific actions and reactions of the road users involved were recorded using a novel observation protocol. Overall, results showed that pedestrians' failure to look towards a driver created the greatest uncertainty in the interaction, with the driver slowing down, but not completely stopping, in response to pedestrians. Looking towards the driver also influenced which road user took priority in driver-driver interactions. Groups of pedestrians were more likely to be given priority than an individual pedestrian, and the use of vehicle-based signals were also associated with taking priority during an interaction. Our observations show the importance of non-verbal communication during road user interactions, highlighting it as an essential area of research in the development of automated vehicles, to allow their safe, cooperative, interactions with other road users. Observations were made on a limited number of interactions to inform challenges facing future automated vehicles. Further work should therefore be done to corroborate and extend our findings, to examine interactions between human road users and automated vehicles in shared space settings.

Keywords: Road user interactions; Pedestrians; Drivers; Automated vehicles; Shared space; Priority

1. Introduction

Road traffic injuries are the eighth leading cause of death globally, and the first for people aged between 5 and 29 years (World Health Organization, 2018). Approximately 1.35 million people are killed on the world's roads each year. More than half of these deaths are amongst vulnerable road users, including pedestrians (World Health Organization, 2018). Reducing road traffic casualties is a target for many national and international agencies (e.g. World Health Organization, 2015) and is particularly important if goals to encourage greater active travel are to be realised (Department for Transport, 2017; European Cycling Federation, 2017).

Communication between road users plays a significant role in road safety. For pedestrians, for example, information about a driver's intentions, actions, and planned behaviour is important if the pedestrian is to assess the driver's actions safely and accurately (e.g. Hamilton, Waterson & Snell, 2014). Research suggests that failure to understand a driver's behaviour may increase a pedestrian's risk of being involved in a collision. For example, Otte, Jansch and Haasper (2012) found that more than half of the 475 pedestrian collisions they analysed were caused by a lack of safety-critical information being signalled to, or recognised, by the pedestrian. An analysis of the underlying causes related to pedestrian collisions showed “faulty diagnosis” was an important factor in pedestrian collisions. This meant that pedestrians had incorrectly assumed that they had been noticed by drivers (Bjorkman et al, 2008). Other research has also confirmed the significance of misinterpretation as a cause of collisions and incidents involving pedestrians. Habibovic and Davidsson (2012) examined the causes of collisions involving vulnerable road users (VRUs) and found that in 70% of cases, the VRU had seen the conflict vehicle but had misunderstood the traffic situation or made an inappropriate plan of action. Habibovic and Davidsson (2012) concluded that helping VRUs correctly understand traffic situations is essential for improving road safety.

In a mixed road setting, successful communication is essential, not only for good traffic flow and safe pedestrian-driver interactions, but also for driver-driver interactions. The importance of nonverbal communication for safe interactions between drivers has been known for decades, with Shor (1964), suggesting the nonverbal communication of driver intentions emerges out of shared social expectations in different situations, with problems arising when drivers do not have shared expectations. For instance, communication signals between drivers can be ambiguous, leading to potential conflicts, and reducing safety if they are misinterpreted (Risser, 1985). Vehicle-based signals are important between drivers, to show intent and planned behaviour, for example when using the left or right indicator signal to change lanes (Kauffmann et al, 2018). However, vehicle-based signals and nonverbal communication between drivers can be interpreted in different ways, which can impact on the potential safety of interactions. This is illustrated by cross-cultural variations in the interpretation of gestures. For example, the honk of a horn may be considered as an expression of anger or irritation in some countries, but in China it is frequently used as a friendly greeting, and in Southern Europe the same signal may be used alongside a rapid acceleration when a driver is merging into a gap in a lane of traffic (Farber, 2016). Receiving feedback about driving behaviour from other drivers is shown to reduce driving violations (Wang et al, 2015), and successful communication between drivers is thought to lead to a more positive social driving climate and safer interactions (Zaidel, 1992).

Understanding how pedestrians and drivers communicate in an urban environment can help us understand how to improve the safety of pedestrian-driver and driver-driver interactions. The successful integration of automated vehicles (AVs) into the road transport system also requires a good understanding of how pedestrians and drivers communicate, and subsequently interact, with these new forms of transport. The Society of Automotive Engineers (SAE) currently provides a six-stage taxonomy of driving automation (SAE levels 0 to 5), where from SAE level 3 onwards, and based on the particular operational design domain, the vehicle (rather than driver) undertakes all aspects of driving control, including object and event detection and response (SAE International, 2018). Therefore, it can be argued that occupants of higher level automated vehicles are not necessarily required to attend to the events of the road, and may, therefore, not engage in any communication with other road users during conflict situations, for example when they are sharing the same road space. It can also be envisaged that SAE Level 4 and 5 vehicles may travel without any occupants at all. Therefore, understanding how interactions between road users currently unfold will provide insights into the interaction strategies and communication requirements of AVs in the future.

In recent years, a growing body of research has focussed on the use of external Human-Machine Interfaces (eHMI) for communicating the intentions or behaviour of AVs (e.g. Habibovic et al, 2018; Clamann, Aubert & Cummings, 2015; Deb, Strawderman & Carruth, 2018, Hensch et al, 2019; Rettenmaier, Albers & Bengler, 2020). However, findings within this research area are mixed. For example, Clamann, Aubert & Cummings (2015) examined the effect of three different eHMI signals used to communicate with a pedestrian about to cross a road. These signals were intended to provide information to support the pedestrian's decision making, regarding whether or not to cross the road. No effect on response times to cross were found for the three different signals, and vehicle behaviour (speed and braking profile) was found to be more important. In contrast, however, Mahadevan et al. (2018) reported that pedestrians preferred to receive explicit information about a vehicle's intentions via an eHMI, rather than deducing the vehicle's intentions from its motion cues. Therefore, a first step in helping resolve some of the discordant findings within research into automated vehicle communication is to understand how communication and interactions currently take place between human road users in a real world setting, to ensure these new forms of technology provide the right, and most clearest, information to all road users (Schieben et al, 2019).

Previous work has shown that the interaction between pedestrians and drivers is influenced by the behaviour of other road users (Rosenbloom, 2009), the speed and stopping distance of vehicles (Sun et al, 2015), as well as pedestrian/driver demographics (e.g. Tom & Granie, 2011). Studies have also highlighted the use of non-verbal communication cues during pedestrian-driver and driver-driver interactions. For example, Sucha, Dostal & Risser (2017) found that signals provided by the driver, such as eye contact, hand waving, or flashing the vehicle lights were important factors in determining whether a pedestrian decided to cross at a marked crossing. Rasouli, Kotseruba & Tsotsos (2017) found that, before crossing a non-signalised crosswalk, pedestrians looked at an approaching car in more than 90% of cases, and provided some form of explicit communication in 15% of cases, such as nodding or using a hand gesture. However, whether the pedestrian actually chose to cross also depended on other factors, including the driver's response. For example, pedestrians were more likely to cross if the driver acknowledged their intention to cross, by slowing down, or stopping the vehicle. This highlights the importance of reciprocal communication between road users during an interaction, in determining how that interaction unfolds – to understand such reciprocal communication, we need to observe the actions and reactions of different road users.

Most previous studies of pedestrian-driver and driver-driver interactions (e.g. Sucha, Dostal & Risser, 2017; Rosenbloom, 2009; Salamati et al, 2013) have been conducted on relatively regulated road sections, with well-understood road rules and formal, universally accepted guidelines (for example, as designated by the Highway Code in the United Kingdom – Department for Transport, 2018). The value of these rules is that they potentially reduce the likelihood of uncertainties in interactions. For example, drivers are expected to give way to pedestrians waiting to cross at designated locations, such as zebra crossings. Likewise, a driver approaching the main road from a side road is required to wait for an appropriate gap in traffic, since the right of way is with the drivers on the main road. However, interactions between road users are likely to be more uncertain and ambiguous in un-signalised road sections, where there are no clear rules of the road or behavioural norms (Kaparias et al, 2012). It can be argued that future AVs may benefit from some type of eHMI in such scenarios, which may communicate the planned actions of the vehicle to other road users, and reduce uncertainty during an interaction. Research is therefore required to further understand pedestrian-driver and driver-driver interactions in such environments, which are not formally governed by rules and standards.

Shared spaces are a good example of traffic environments that do not function based on formal rules and standards. The shared space concept is an urban design approach where different types of road users move and interact with each other on the basis of informal social protocols and negotiation (Hamilton-Baillie, 2008). Interactions in shared spaces normally take place between low speed vehicles and other road users, in potentially ambiguous situations, where the intended actions of either driver or pedestrian are unclear, and it is not obvious who has priority. Shared spaces are commonly seen as specifically designed and engineered to promote safe interaction between different types of road users. They may use specific design principles, such as limited demarcation between roads and footpaths, restriction of vehicle speeds through street design, and clearly marked access points to the shared space (Karndacharuk, Wilson & Dunn, 2014). Despite a growth in popularity of the concept of specifically-designed shared spaces (as evidenced by the introduction of specific transport planning guidance related to shared spaces, e.g. Department for Transport, 2011), they remain relatively uncommon in urban contexts. Car parks (also known as parking lots in North America), however, represent a common example of a shared space, due to the use of social protocols and negotiation during interactions between drivers (searching for, or leaving, a parking space) and pedestrians (travelling to, or from, their vehicle). Car parks therefore provide an important, but under-researched, context for understanding interactions between different road users.

Shared spaces (including car parks) are associated with lower vehicle speeds, and these lower speeds have been shown to lead to more conflicts between road users (Salamati et al, 2013), where a conflict is defined as "an observational situation in which two or more road users approach each other in space and time to such an extent that a collision is imminent if their movements remain unchanged" (Svensson, 1998). However, it can also be argued that shared spaces, such as car parks, may lead to a reduction in conflicts. This can be due to increased vigilance and better cooperation between road users, to manage the higher number of likely interactions (e.g. Kaparias et al, 2013). Such shared spaces, therefore, provide a valuable context in which to study pedestrian-driver and driver-driver interactions, to understand how potential conflicts are resolved between the two types of road user.

With regards to designing more successful communication strategies for future AVs, this type of observation can be useful for understanding how priority is determined during conflicts between different road users. This knowledge may, for example, help avoid deadlock situations, where a lack of communication prevents either actor from moving forward (Imbsweiler et al, 2018). Shared space settings have been highlighted as an important scenario to be understood when considering the introduction AVs into mixed traffic, and the behaviour of AVs in a shared space is an important research question (Parkin et al, 2018). Therefore, a first step towards addressing this research question is to investigate the interactions between existing road users in such a setting.

To further investigate the factors which determine how priority is established between different road users in a shared space, this study used a bespoke observation protocol (Dietrich et al, 2018) to investigate road-user behaviour in a railway station car park in Leeds, UK. One key aim of the study was to establish how behaviours in the initial phase of an interaction were associated with the final outcome of the interaction. The study was part of the wider EU-funded project 'interACT' (grant number 723395), the overall goal of which was to understand current road user interactions, and apply this knowledge to AV strategies for communication and interaction. Specifically, our two main research questions were: 1) How are behaviours in the initial phases of an interaction, such as looking and hand signals, related to the latter phases of that interaction; and 2) What are the factors that determine which road user takes priority in an interaction?

2. Method

2.1 Observation site

As part of the European interACT project, observations were recorded at three European locations (Leeds, UK; Athens, Greece; Munich, Germany). This paper presents a detailed analysis of observations and their sequencing at only the Leeds location, to focus on interactions within a shared space and in a specific cultural context. A summary of observations across the three locations can be found in Lee et al (2019). For the purposes of this study, an interaction was defined as a situation when one road user may need to react in response to another road user (see Dietrich et al, 2018, for further details on definition of interaction in the wider context of this research, and see Markkula et al, 2020, for a more detailed conceptual framework in relation to the definition of interactions between road users).

A medium-sized car park located at the central railway station in Leeds, United Kingdom, was selected as the observation site (see Figure 1). As this location was at a busy city-centre railway station, with high footfall due to people leaving and entering the railway station via the car park, it provided a high frequency of both pedestrian-driver and driver-driver interactions, at low speeds (generally below 25 km/h). It was also considered a shared space due to the relatively high volumes of both pedestrians and vehicles. The car park was observed across eight two-hour sessions, between the 5^{th} and the 8^{th} December, 2017, with morning observations occurring between 9:30am and 11:30am, and afternoon observations occurring between 2:30pm and 4:30pm. All observations were carried out during daylight. A GoPro camera was also positioned at an elevated location on the roof of an adjacent building. The camera had a field of view covering the entire area of the car park and was used to record vehicle and pedestrian behaviours during the observation periods.

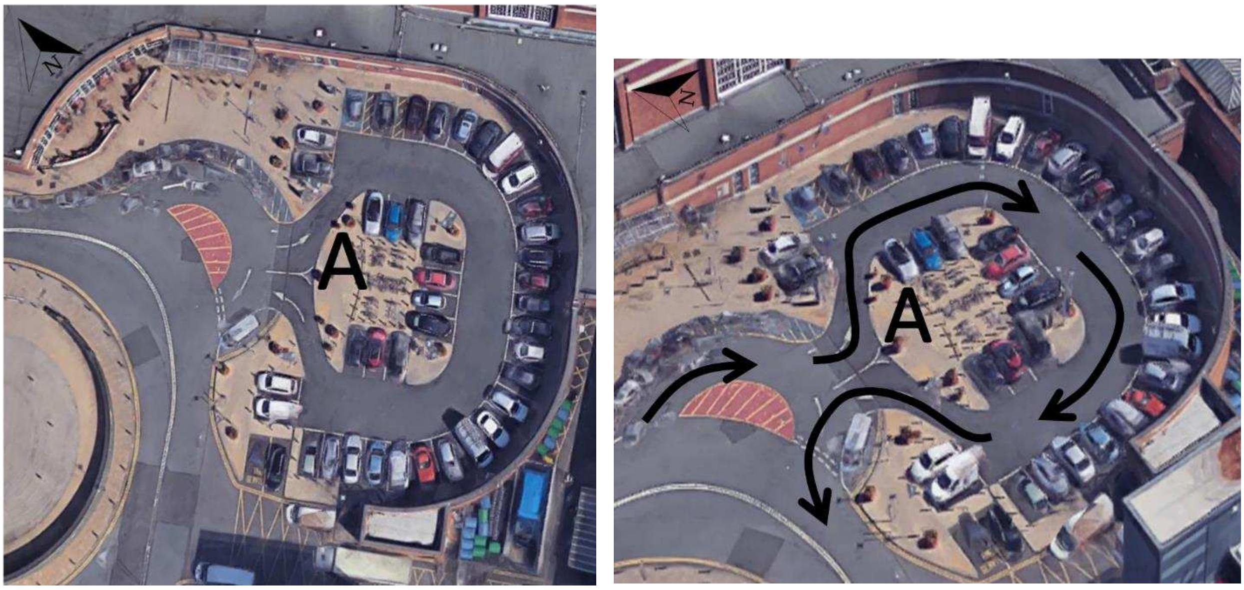

Figure 1. (Left) Overhead satellite image of observation site. (Right) 3-dimensional image of observation site, with directional arrows showing general flow of vehicle traffic through car-park. Letter ‘A’ indicates observer position. Map and imagery data © 2019 Google.

2.2 Procedure

Two observers were positioned at location A in Figure 1. This position reduced the likelihood of the observers influencing the interactions of the other road users. Field observers were used to capture as much information as possible from the road user interactions, including aspects of the interaction that may not be apparent or visible from video recordings, such as gestures or head movements that may be obscured from a camera's viewpoint. Having field observers close to the location of any interaction helped improve the accuracy of the behavioural observations, compared with, for example, viewing only a video captured from a remote location.

Each observer was equipped with a tablet, loaded with an html-based app for logging details of the interactions observed (see Figure 2). The app allowed observers to record a range of different actions and information (see Table 1), including the sequence in which these actions took place. The actions and categories of information that could be recorded were developed from an initial exploratory pilot study designed to identify common observations and behaviours. Observers were also able to provide free-text notes about their observations to describe any ambiguities of the recorded categorical information. The app also allowed observers the ability to provide pictorial representations of the interactions observed, marking the initial placement and direction of movement for the interacting participants.

The app allowed observers to record details of an interaction as it unfolded. in real time. This app was developed as part of the wider EU-funded interACT project. Further details about the app are given in Dietrich et al (2018). Previous studies of road-user interactions have used similar observational methods, with field observers recording details of behaviours, e.g. at pedestrian crossings (Rosenbloom, 2009) and in urban areas (Sucha, Dostal & Risser, 2017). Other methodological approaches include using video recordings to collect data about interactions (Kaparias et al, 2015), or surveys, to assess self-reported behaviours (e.g. Sisiopiku & Akin, 2003). The observation protocol in the current study used direct field observations made in real time, but these were supported by subsequent annotations and diagrams by the observers to adequately describe the interactions. All interactions were recorded on video by the GoPro camera, positioned at an elevated location above the car park. The video recordings were not used to directly code the data, which was done by the field observers in real time. However, the videos allowed verification of the original coding and behaviours recorded by the field observers, particularly when the sequencing and nature of interactions was unclear from the data recorded through the HTML app. The use of the recording app, and the assignment of one observer to each actor in the interaction, allowed the detailed recording of event sequences.

Ethical approval for the study was obtained from the University of Leeds Ethics Committee (AREA 17-010).

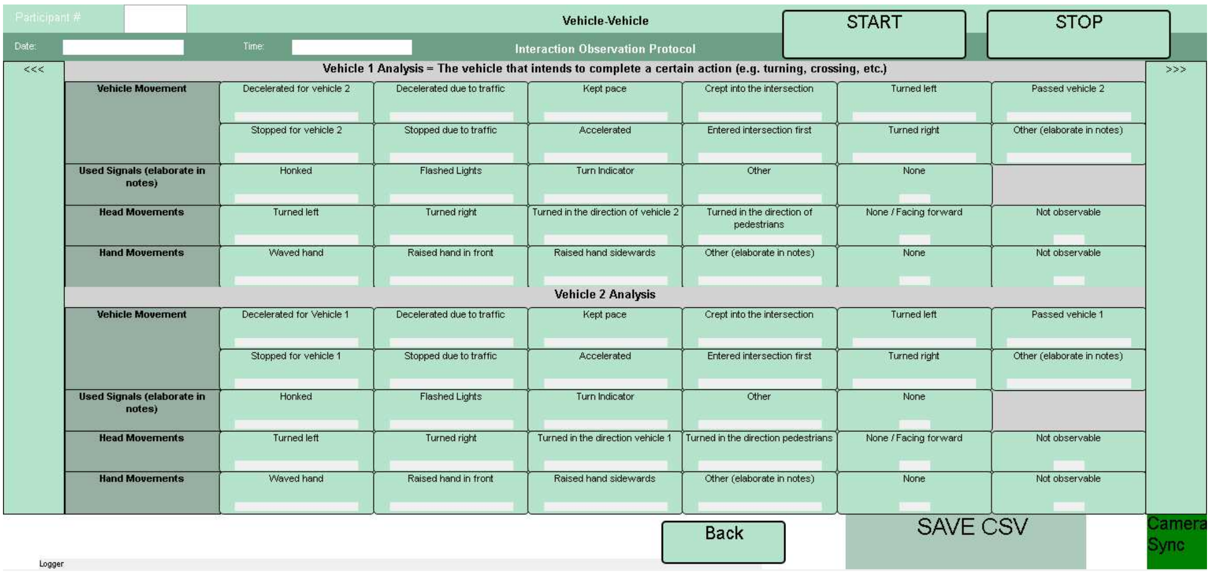

Figure 2. Screenshot from html-based app used for recording events and information related to each observed interaction for driver-driver interactions. Similar interface used for logging pedestrian-driver interactions.

Table 1. Categories of information recorded about each observed pedestrian-driver and driver-driver interaction via the html-based app.

Interaction type	**Broad category**	**Specific action / information**	**Description**
Pedestrian – Vehicle	General information	Weather	Weather conditions at time of interaction
		Individual or group of pedestrians	Whether an individual or group of pedestrians were involved in the interaction
		Gender of pedestrian/s	Gender of pedestrian/s
		Potential distraction of pedestrian/s	Whether pedestrian was potentially distracted, e.g. using mobile phone
		Additional notes	Any additional comments or notes about the interaction
	Pedestrian analysis	Hand movements	Whether pedestrian/s used any hand movements
		Head movements	Whether pedestrian/s turned their head at any point or looked straight ahead
		Looking at other road user	Whether pedestrian/s looked at the driver / vehicle involved in the interaction
		Movement and position	Relative movement and position of pedestrian, e.g. accelerating or decelerating, stopped, left or right of vehicle, whether they passed the vehicle
	Vehicle / Driver analysis	Hand movements	Whether driver used any hand movements
		Head movements	Whether driver turned their head at any point or looked straight ahead
		Vehicle type	Type of vehicle, e.g. car, van
		Scenario	General description of the situation, e.g. vehicle was entering or leaving car park, entering or leaving a parking space

		Use of signals	Whether driver used any explicit signals such as flashing headlights or honking horn
		Vehicle movement	Relative movement and position of vehicle, e.g. accelerating / decelerating, keeping pace, stopped for pedestrian
Vehicle – Vehicle	General information	Weather	Weather conditions at time of interaction
		Direction of approach (vehicle 2 relative to vehicle 1)	Whether vehicle 2 approached vehicle 1 from front / back / left / right
		Vehicle type (1 and 2)	Type of vehicle, e.g. car, van
		Additional notes	Any additional comments or notes about the interaction
	Vehicle / Driver analysis (recorded separately for vehicle 1 and vehicle 2)	Hand movements	Whether driver used any hand movements
		Head movements	Whether driver turned their head at any point or looked straight ahead
		Use of signals	Whether driver used any explicit signals such as flashing headlights or honking horn
		Vehicle movement	Relative movement and position of vehicle, e.g. accelerating / decelerating, keeping pace, stopped for pedestrian

2.3 Recording interactions

For pedestrian-driver interactions, one of the observers identified a pedestrian who was likely to interact with a vehicle, based on their trajectory and the trajectories of nearby vehicles. The selection of this pedestrian was also indicated to the other observer. One of the observers then began recording the actions and events related to the pedestrian, while the other recorded those related to the driver and vehicle. A similar process was carried out for driver-driver interactions – one observer initially selected a vehicle for observation, prior to the vehicle signalling or changing trajectory. This observer recorded the actions and details related to that driver and vehicle (referred to as Vehicle 1 in this paper). The second observer focused on the vehicle that was about to interact with Vehicle 1 (this vehicle is referred to as Vehicle 2 in this paper). Therefore, for both pedestrian-driver and driver-driver interactions, each observer focused only on one of the parties involved in the interaction. This ensured no details were missed during the interaction due to divided attention. Interactions took place across the whole observation location and not in one specific place. The central position of the observers allowed them to have a good view of any interactions taking place within the car park area.

As the pedestrians and vehicles of interest were selected in advance, in some cases they did not end up interacting with one another. In those situations, the observation was not saved, so only situations in which an interaction occurred were included in the analysis. In other situations, it is possible that a pedestrian and vehicle, or two vehicles, may have had an unexpected interaction, which was not anticipated by the observers based on their initial trajectories, or which started before the observers had seen one of the interaction parties. These situations were also excluded if the full interaction process had not been observed, as it was deemed important to capture the whole movement pattern of both interaction parties. The aim of the study was to provide an exploratory snapshot of the typical interactions which occurred in this type of shared space setting. Although it is possible that some interactions were missed, the range of locations and interaction types which were observed provide confidence that the typical interaction characteristics for this location were captured.

The actions and events related to each road user were recorded for the immediate periods before and after the interaction, as well as during the interaction itself, to capture precursor and subsequent behaviours. This procedure was practiced extensively in a number of pilot observations. Following completion of the interactions, the observers conferred to verify the accuracy of their recordings, and the sequencing of events.

Sixty six pedestrian-driver and 124 driver-driver interactions were observed using the procedure described above. Summary information about these interactions is given in Table 2. Although the sample of 190 interactions is relatively limited, it provides a rich body of data containing extensive, sequential information about the actions and reactions of road users during those interactions.

Table 2. Descriptive details of pedestrian-driver and driver-driver interactions.

Interaction type	**Details**	**Value**
Pedestrian-Driver	Estimated age of pedestrian/s*	18-30 = 39% 31-60 = 61% 61+ = 6%
	Individual or Group	Individual = 73% Group = 27%
	Gender of pedestrian/s	Male (individual or group) = 50% Female (individual or group) = 24% Male and female (group) = 26%
	Scenario (vehicle)	Driving through car park* = 70% Entering parking space = 17% Leaving parking space = 13%
	Weather	Sunny = 42% Overcast = 55% Other = 3%
Driver-Driver	Vehicle type	Car = 95% Van / Truck = 2% Not recorded = 3%
	Vehicle 2 approach to Vehicle 1	From behind = 36% From front = 15% From left / right = 49%
	Weather	Sunny = 16% Overcast = 76% Other = 8%

* Vehicles driving through car park were generally either attempting to pick up or drop off a passenger, or were looking for a vacant parking space

2.4 Analysis

The main variable of interest in our analysis was the outcome of the interaction. This was defined in two ways. The first was the movement behaviour of the vehicles involved in the interaction – whether they 1) Maintained their speed throughout the interaction, not stopping or decelerating; 2) Decelerated during the interaction, but without coming to a complete stop; 3) Stopped completely during the interaction. The second approach to defining the outcome of the interaction was in terms of which road user took priority. Here, the road user assigned as taking priority was the one that passed in front of the other road user, after the other road user had adjusted their path (e.g. slowing and stopping) to allow this.

The outcome of the interaction was compared against other actions and factors related to the road users involved. For example, for pedestrian-driver interactions, we examined whether the pedestrian looked at the driver / vehicle. For driver-driver interactions, looking behaviour was again compared against the outcome of the interaction. The use of signals, by either driver was also compared against the outcome of the interaction.

Frequencies of head and hand movements used by pedestrians and drivers during their interactions are also reported.

We provide cross-tabulations of the various actions and reactions observed during pedestrian-vehicle and vehicle-vehicle interactions, reporting both observed and expected counts. Since the expected counts in some of the cells of these cross-tabulations were less than five, Fisher's exact test has been used to assess whether there are significant interactions between the different categories of behaviour. Adjusted standardised residuals (ASRs) are reported to aid interpretation of these cross-tabulations. Convention suggests ASRs greater than two indicate the observed count in a cell significantly differs from the expected count (Sharpe, 2015). Due to the exploratory nature of this study, we also highlight potential trends suggested within cross-tabulations but where ASRs may be less than two, although caution should be taken in making firm conclusions about any such trends. Cramer's V is reported as a measure of effect size, for those cross-tabulations that show a significant interaction between variables.

3. Results

3.1 Pedestrian – Driver interactions

Sixty-six pedestrian-driver interactions were observed. The mean duration of these interactions (from the points at which the observers started and stopped recording the actions of those involved in the interaction) was 7.9 seconds (standard deviation = 4.6 seconds). The majority of interactions (67%) took place as the vehicle was driving through the car park, with fewer interactions taking place when the vehicle was entering a parking space (15%) or leaving a parking space (12%). The type of scenario (e.g. driving through car park or entering / leaving a parking space) was not recorded for a small proportion (11%) of interactions. Some type of vehicle-based signal, such as a flash of headlights, turn indicator or horn, was used in 11% of interactions.

Use of hand and head movements

For all observed interactions, it was possible to observe whether the pedestrian used hand or head movements. However, it was not possible to observe the driver's hands or head in

14 of the 66 interactions, therefore, percentages reported for drivers in this section exclude these 14 interactions, for which data could not be recorded.

Hand movements were used by the pedestrian in 17% of interactions, and by the driver in 12% (6 out of 52) of interactions. These tended to be used as a thank you to the other road user, or to indicate right of way. Head movements (turning to the left or right) were used by pedestrians in 42% of interactions. Drivers used a head movement in 83% (43 out of 52) of interactions. The large majority of these driver head movements involved them turning to look towards the pedestrian (81% of head-turns by the driver, or 42 out of 52, were towards the pedestrian involved in the interaction).

Looking at the vehicle and driver

The coding structure for observations allowed observers to record whether a pedestrian looked directly at a driver, and this occurred in 32% of interactions. It was not always possible to accurately confirm whether the pedestrian looked directly at the driver. If there was uncertainty about whether the driver was actually looked at directly, the coding structure allowed observers to record whether the pedestrian looked in the general direction of the driver and their vehicle. This was recorded for 38% of interactions. These two categories were collapsed into one for subsequent analysis, labelled 'looking towards the driver', because, even when the observer could not confirm for certain whether the pedestrian looked directly at the driver, it was reasonable to assume the pedestrian was looking in the driver's general direction. Pedestrians looked towards the driver in 65% of interactions.

Does looking towards the driver result in a different type of interaction outcome?

To establish if driver behaviour was influenced by the pedestrian's looking behaviour, we coded observed vehicle response into three categories: i) no change in speed ii) a deceleration, without coming to a complete stop, or iii) stopping completely. Table 3 shows the observed counts of each category of interaction, as well as expected counts, based on row and column totals, and the adjusted standardised residuals for observed vs expected counts. Adjusted standardised residuals are presented as unadjusted residuals are relatively conservative (see Everitt, 1992).

A Fisher's exact test on these data showed a significant association between a pedestrian's looking behaviour and the driver's behaviour, during their interaction ($p = .019$, Cramer's $V = 0.36$). Examination of the observed and expected counts, and their associated ASRs, suggests that: not looking towards the driver was associated with an increased likelihood that the driver would decelerate, whereas looking towards the driver was associated with a slightly increased likelihood the driver would either continue at the same speed or come to a complete stop.

Table 3. Observed counts, expected counts, and adjusted standardised residuals when comparing pedestrian looking behaviour against driver behaviour.

	Driver behaviour		
	Maintained speed without decelerating or stopping	Decelerated but did not come to complete stop	Stopped completely

Pedestrian did not look towards the driver	Observed count	4	15	4
	Expected count	6.6	9.4	7.0
	Adjusted standardised residual	-1.50	2.94	-1.67
Pedestrian looked towards the driver	Observed count	15	12	16
	Expected count	12.4	17.6	13.0
	Adjusted standardised residual	1.50	-2.94	1.67

Which road user was given ‘priority’ in the interaction was also examined, based on whether or not the pedestrian looked at the vehicle / driver. A road user was defined as being given ‘priority’ if they were allowed to continue with their movements, whilst the other road user in the interaction waited for them to complete these movements. For example, if the driver stopped and allowed the pedestrian to cross in front of them, priority was allocated to the pedestrian in this situation. A small proportion of interactions (15%) did not involve either road user having priority, for example if neither the driver nor pedestrian had to adjust or halt their movements. In 65% of interactions it was the pedestrian who took priority, compared with only 20% of interactions where the driver took priority.

Table 4 shows the observed and expected counts of interactions, where pedestrian looking behaviour towards the driver was considered, when establishing who was given priority during the interaction. A Fisher’s exact test suggested no significant association between where the pedestrian looked and which road user in the interaction took priority (p = .802, Cramer’s V = 0.07).

Table 4. Observed counts, expected counts, and adjusted standardised residuals when comparing pedestrian looking behaviour against priority.

		Priority		
		Neither pedestrian or vehicle	Pedestrian	Driver
Pedestrian did not look towards the driver	Observed count	4	14	5
	Expected count	3.5	15.0	4.5
	Adjusted standardised residual	0.37	-0.53	0.31
Pedestrian looked towards the driver	Observed count	6	29	8
	Expected count	6.5	28.0	8.5
	Adjusted standardised residual	-0.37	0.53	-0.31

Are groups of pedestrians associated with a different type of interaction with drivers than individual pedestrians?

Driver behaviour during the interaction, in terms of whether they decelerated in response to the pedestrian, stopped for the pedestrian, or did neither, was compared for interactions that involved either individual pedestrians or groups of pedestrians. Table 5 shows the observed and expected counts in each of these categories. A Fisher’s exact test suggested no significant association between number of pedestrians and subsequent driver behaviour (p = .418, Cramer’s V = 0.17)

Table 5. Observed counts, expected counts, and adjusted standardised residuals when comparing the number of pedestrians (individuals or a group) against driver behaviour.

		Driver behaviour		
		Maintained speed without decelerating or stopping	Decelerated but did not come to complete stop	Stopped completely
Individual pedestrian	Observed count	16	19	13
	Expected count	13.8	19.6	14.5
	Adjusted standardised residual	1.33	-0.36	-0.93
Group (2+) of pedestrians	Observed count	3	8	7
	Expected count	5.2	7.4	5.5
	Adjusted standardised residual	-1.33	0.36	0.93

In addition to examining the driver's behaviour during the interaction, in terms of whether they decelerated, stopped or neither, priority was also examined for interactions involving individual or groups of pedestrians. Observed and expected counts are shown in Table 6. A Fisher's exact test suggested a significant association between the number of pedestrians involved in the interaction (individual or group) and which road user took priority in the interaction ($p = .027$, Cramer's $V = 0.31$). Comparison of the observed and expected counts suggests interactions involving a single pedestrian were more likely to result in the driver taking priority. Interactions involving a group of pedestrians were more likely to involve the pedestrians taking priority.

Table 6. Observed counts, expected counts, and adjusted standardised residuals when comparing pedestrian looking behaviour against priority.

		Priority		
		Neither pedestrian or vehicle	Pedestrian	Driver
Individual pedestrian	Observed count	7	28	13
	Expected count	7.3	31.3	9.5
	Adjusted standardised residual	-0.21	-1.90	2.46
Group (2+) of pedestrians	Observed count	3	15	0
	Expected count	2.7	11.7	3.5
	Adjusted standardised residual	0.21	1.90	-2.46

3.2 Driver-Driver interactions

In addition to the pedestrian-driver interactions, 124 driver-driver interactions were recorded for this study. The mean duration of these interactions (from the points at which the observers started and stopped recording the actions of those involved in the interaction) was 12.1 seconds (standard deviation = 8.9 seconds). Almost three quarters of these interactions (73%) involved a parking manoeuvre by at least one of the vehicles. Over half of the interactions (54%) also involved at least one of the vehicles reversing. Some form of vehicle-based signal (e.g. use of horn, flash of headlights, or use of turn indicators) was used in 33% of interactions. The majority of these signals (23% of all interactions) were use of the turn indicators, with much less use of the headlights (2% or 3 out of 124 interactions) or the horn (1% or 1 out of 124 interactions). Some other form of signal was used in 8% of interactions (e.g. reverse or brake lights).

Use of hand and head movements

It was not possible to observe one or both drivers' hands in 19 of the 124 interactions. Similarly, it was not possible to observe one or both drivers' head movements in 20 of the 124 interactions. Therefore, percentages reported for driver hand and head movements in this section exclude these 19 and 20 interactions for which data could not be recorded, respectively. For the remaining results, only 10% of interactions (10 out of 105) involved hand movements from one or both drivers, but head movements were used in 56% of interactions (58 out of 104. Almost all of the head movements involved in these interactions (55 out of 58) were due to at least one of the drivers looking towards the other driver or vehicle.

Looking towards the other driver / vehicle

As alluded to above, the vast majority of head movements made by a driver were to look towards the other driver involved in the interaction. For driver-driver interactions it was even more difficult than in pedestrian-driver interactions to confirm with certainty whether one driver looked directly at the other driver, due to the windscreen and moving speeds involved. Therefore, looking behaviour was only categorised as 'looking towards the other driver', acknowledging the potential uncertainty in whether the other driver was directly looked at, or not. Results showed that at least one of the drivers turned their head to look towards the other driver in 53% of interactions in which head movements could be observed (55 out of 104 interactions). A third of these interactions involved both drivers turning to look towards each other, but it was more common for only one of the drivers to look towards the other driver. As the observation location was a car park, this often occurred if one of the drivers was looking for a parking space or waiting to collect pedestrians, and attention was therefore not directed overtly towards other drivers.

Does looking towards the other driver result in a different type of interaction outcome?

We examined whether a driver's look towards another driver in the interaction influenced behaviour of the second driver. The response of the second driver was characterised as either no change in vehicle speed, a deceleration of the vehicle, without a complete stop, or stopping completely. **Error! Reference source not found.** shows counts of each category of interaction, based on the looking behaviour of one of the drivers and the response from the other driver. Note that each unique interaction could contribute two values to the observed counts in this cross-tabulation, as there were two drivers involved. This is why the total observed count is greater than the total number of interactions. A Fisher's exact test did not suggest a significant association between the looking behaviour of a driver and the response of the other driver ($p = .54$, Cramer's $V = 0.09$).

Table 7. Observed counts, expected counts, and adjusted standardised residuals when comparing driver looking behaviour against other driver's response.

		Other driver behaviour		
		Maintained speed without decelerating or stopping	Decelerated but did not come to complete stop	Stopped completely
Driver did not look towards the other driver	Observed count	58	15	27
	Expected count	58.4	12.7	28.9
	Adjusted standardised residual	-0.12	1.06	-0.65
Driver looked towards the other driver	Observed count	43	7	23
	Expected count	42.6	9.3	21.1
	Adjusted standardised residual	0.12	-1.06	0.65

The connection between the looking behaviour of each driver involved in the interaction and which driver took priority was also examined. Table 8 shows the counts of interactions involving different looking behaviours and which driver took priority (if either did) during the interaction. A Fisher's exact test confirmed a significant interaction between the looking behaviour of a driver and whether or not they then gained priority ($p = .025$, Cramer's $V = 0.25$). Examining the ASRs suggests that when both drivers looked towards the other driver, driver 1 was more likely to take priority in that interaction. When neither driver looked towards each other, neither driver took priority, and this occurred in a diverse range of interaction types. The residuals also suggest a trend that priority is taken by the driver who looks towards the other vehicle. For example, when driver 1 looked towards the other driver, the number of interactions in which that driver took priority was higher than expected. Likewise, when driver 2 looked towards the other driver, the number of interactions in which they took priority in that interaction was also higher than expected. However, the ASRs related to these trends do not reach two, and we should therefore treat this interpretation with caution.

Table 8. Observed counts, expected counts, and adjusted standardised residuals when comparing driver looking behaviour against priority.

		Priority		
		Neither driver	Driver 1	Driver 2
Both drivers looked towards the other driver	Observed count	3	8	7
	Expected count	6.4	3.8	7.8
	Adjusted standardised residual	-1.81	2.65	-0.43
Driver 1 looked towards the other driver	Observed count	4	6	9
	Expected count	6.7	4.0	8.3
	Adjusted standardised residual	-1.43	1.24	0.37
Driver 2 looked towards the other driver	Observed count	5	2	11
	Expected count	6.4	3.8	7.8
	Adjusted standardised residual	-0.74	-1.11	1.63
Neither driver looked	Observed count	32	10	27
	Expected count	24.5	14.5	30.0
	Adjusted standardised residual	2.84	-1.98	-1.11

towards the other driver

Is the use of signals by the driver associated with a different type of interaction?

To assess the effect of signals on behaviour, the use of various vehicle signals (e.g. flash of headlights, use of turn indicators, honk of horn) by either driver, was used to understand the opposing driver's response in that interaction. Table 9 shows the counts of interactions that involved use of signals by either driver, and the behavioural response of the other driver. Note that, in each case, the driver did or did not use a signal. Therefore, each unique interaction could contribute two values to the observed counts in this cross-tabulation, resulting in a total observed count greater than the actual number of interactions. A Fisher's exact test suggested a marginally significant association between the use of a signal by one of the drivers and the driving response of the other driver ($p = .054$, Cramer's $V = 0.15$). In other words, if one of the drivers used a signal during the interaction, the other driver was less likely to maintain their speed without decelerating or stopping.

Table 9. Observed counts, expected counts, and adjusted standardised residuals when comparing driver 1 use of a signal against driver 2 behaviour.

		Other driver behaviour		
		Maintained speed without decelerating or stopping	Decelerated but did not come to complete stop	Stopped completely
Driver did not use a signal	Observed count	111	39	53
	Expected count	104.0	40.9	58.1
	Adjusted standardised residual	2.32	-0.79	-1.87
Driver used a signal	Observed count	16	11	18
	Expected count	23.0	9.1	12.9
	Adjusted standardised residual	-2.32	0.79	1.87

The use of signals by either or both drivers was also compared, in relation to which driver took priority in the interaction, see Table 10. A Fisher's exact test confirmed a significant interaction between the use of signals and which driver took priority ($p = .040$, Cramer's $V = 0.23$). When driver 1 used a signal this led to an increased likelihood that they also took priority in the interaction. However, when neither driver used a signal, driver 1 was less likely to take priority.

Table 10. Observed counts, expected counts, and adjusted standardised residuals when comparing signal use of drivers against priority.

		Priority		
		Neither driver	Driver 1	Driver 2
Both drivers	Observed count	3	1	1
	Expected count	1.8	1.0	2.2

used signals	Adjusted standardised residual	1.17	-0.05	-1.08
Driver 1 used signal	Observed count	7	11	7
	Expected count	8.9	5.2	10.9
	Adjusted standardised residual	-0.88	3.17	-1.76
Driver 2 used signal	Observed count	2	2	6
	Expected count	3.5	2.1	4.4
	Adjusted standardised residual	-1.07	-0.08	1.09
Neither driver used signal	Observed count	32	12	40
	Expected count	29.8	17.6	36.6
	Adjusted standardised residual	0.89	-2.65	1.33

4. <u>Discussion</u>

Understanding interactions between road users can help improve road safety and support ongoing work in the development of methods that AVs may use to communicate. We observed pedestrian-driver and driver-driver interactions at a UK car park, categorising the actions that took place in each of those interactions. We used these data to examine how the actions of one of the road users in the interaction were associated with the reactions of the other road user. A car park was selected as the observation site because it represents a shared space between pedestrians and drivers and was therefore likely to produce potentially ambiguous interaction situations, not governed by explicit rules of the road or conventional norms. Studying these types of interactions is beneficial in this context, as they rely solely on interpreting the actions and signals between the two parties. Studying these interactions also allows an appreciation of the cooperative behaviour required in the absence of clear road infrastructure, such as is present at pedestrian crossings or junctions.

4.1 Pedestrian-Driver interactions

Hand gestures were relatively rare in pedestrian-driver interactions by either road user. This is consistent with other research suggesting explicit communication between pedestrians and drivers is rare (e.g. Lee et al, 2019; Dey & Derkin, 2017). However, the proportion of interactions that involved use of hand gestures was slightly higher than that found by Lee et al (4% of pedestrian-driver interactions in Lee et al (2019), compared with up to 17% of pedestrian-driver interactions in the current analysis). This could be explained by the fact that the observations reported here were at a shared space that may have produced more ambiguous interactions than in the road crossing situation observed by Lee et al. Hand gestures are probably useful when an interaction is ambiguous, as a method for resolving that ambiguity. The slow speeds used in the shared space setting may also have allowed more use of hand gestures for successful and observable communication, compared to faster speed settings, such as those used in Lee et al. (2019).

Our first main research question was based on investigating how initial behaviours in an interaction relate to the final outcome of that interaction. Results showed that the driver's behaviour appeared to be influenced by whether or not the pedestrian looked towards them. Drivers were more likely to either stop completely, or continue at their current speed if the pedestrian looked towards them, whereas they were more likely to slow down, but without stopping, if the pedestrian did not look towards them. Previous work has shown that if pedestrians look at a driver at crossing, there is increased likelihood that the driver will yield (Gueguen, Meineri & Eyssartier, 2015). However, our observations also suggest drivers may equally be encouraged to maintain their current speed when a pedestrian looks towards them. Our interpretation of these results is that by looking towards the driver, the pedestrian is prompting the driver to make a clear decision about their behaviour, either to stop completely or to continue on their present course. Not looking towards the driver potentially creates uncertainty for the driver, where it is not clear whether the pedestrian has seen them, and/or not obvious how the pedestrian is likely to behave. Slowing down may reflect this uncertainty in the driver. Interpreting the driver's action in this situation is also aided by information about the pedestrian's position during the interaction. For example, if the pedestrian was directly in the path of the driver this is more likely to prompt them to stop completely, regardless of where the pedestrian was looking. Unfortunately, however, this detailed level of pedestrian position was not recorded during our observations. One caveat with our interpretation of these results is that it was not possible to determine precisely whether the pedestrian was looking directly at the driver, or in the general direction of the driver/ their vehicle. However, it is can be argued that pedestrians are able to communicate their intentions and influence driver behaviour by simply looking in the general direction of a driver /vehicle, without looking directly at them, or making eye contact, (e.g. Kooij, Schneider, Flohr & Gavrila, 2014; Rasouli, Kotseruba & Tsotsos, 2017).

Our second main research question related to which factors were related to which of the road users took priority in the interaction. Interactions were therefore also assessed on which of the road users took priority (defined by which slowed down or stopped for the other road user, allowing them to pass in front of them). A small proportion (15%) of interactions did not involve either road user taking priority. Pedestrians took priority in 78% of interactions that involved the priority being taken by one of the road users. This is higher than has been found in other scenarios involving the interaction of pedestrians and drivers. Varhelyi (1998) studied interactions at a non-signalised zebra crossing on a 50 km/h mid-block road in Sweden, and found that pedestrians had priority in only 5% of these. Observations of driver yielding behaviour at 10 uncontrolled crosswalks (Crowley-Koch & van Houten, 2011) suggested pedestrians were given priority on average during 12% of interactions. This value increased, however, when the pedestrian extended their arm, or raised their hand towards the driver, accounting for up to 45% of interactions. This study took place in the United States, but there may be cultural differences in yielding behaviour between different nations. For example, Ferenchak and Marshall (2018) recorded whether pedestrians or vehicles acquiesced during interactions, at 37 highly intermodal intersections in India. Their data suggests the proportion of interactions in which the pedestrian took priority was 54%, when averaged across all 37 interactions.

The fact that the space for our car park site was shared between the different road users in our study is likely to account for the high proportion of interactions in which the pedestrian took priority. As the location was adjacent to a busy city-centre railway station, it consisted of a high volume of pedestrians crossing through it. As pedestrian numbers increase, particularly relative to vehicle numbers, the probability that a driver will give priority to a pedestrian increases (Ferenchak & Marshall, 2018). As our observed site was a car park, it resulted in slow vehicle speeds, and as a shared space in which high volumes of pedestrians were expected, interactions were likely to be cooperative in nature. In contrast, previous studies have often focused on crossing scenarios on higher speed roads. For example, Varhelyi's (1998) observations took place on a 50 km/h road, at a mid-block position i.e. not near a junction, meaning drivers were unlikely to be slowing down or driving more cautiously. Shared space settings such as the car park used in this study require greater cooperation and negotiation between users of the space (Hamilton-Baillie, 2008) than other road and urban contexts, and it is in such settings that communication between AVs and other road users may be most important, particularly given that the current development and introduction of AV systems often takes place in shared public realm spaces (Merat et al, 2018).

Our observations did not suggest that pedestrians were more likely to have the priority if they looked towards the driver. This is in contrast to previous research on pedestrian crossing scenarios (e.g. Gueguen, Meineri & Eyssartier, 2015; Ren, Jiang & Wang, 2016), which suggests looking towards the driver, particularly eye contact, can increase the likelihood that the driver will yield to the pedestrian, and the distance they decelerate from to allow them to cross a road. The effect of looking towards the driver in terms of who takes priority may vary depending on the situation. In a road crossing situation, particularly at a designated crossing location, it is clear what the pedestrian's intention is and looking at a driver is likely to increase compliance with formal regulations or informal social norms (e.g. Hamlet, Axelrod & Kuerschner, 1984) that promote yielding to pedestrians. In a shared space setting, however, the interactions may be more ambiguous, and the intentions and planned actions of the pedestrian may be less clear. Looking towards the driver appears to reduce the uncertainty in the interaction, but this can equally result in either the driver or the pedestrian taking priority. It is also possible that the shared space setting and the high volume of pedestrians led to fewer pedestrians looking towards drivers due to an assumption that drivers would be driving cautiously and react accordingly in the presence of pedestrians.

Priority in pedestrian-driver interactions was, however, influenced by the number of pedestrians involved. Drivers were more likely to give priority to a group of pedestrians, than a single pedestrian. This supports previous research that shows an increase in driver yielding behaviour when groups of pedestrians are waiting to cross a road, compared with a single pedestrian (e.g. Himanen & Kulmala, 1988; Sucha, Dostal & Risser, 2017).

4.2 Driver-Driver interactions

Explicit vehicle-based signals were used in a third of interactions between drivers, but hand gestures were relatively rare, used in only 10% of interactions. This suggests that currently, signals from the vehicle itself are more common than signals from the driver, which tend to be infrequent. This supports other work that has shown the relative importance of vehicle movements and the associated implicit communication, compared with explicit communication by the driver (e.g. Dey & Derkin, 2017). Research has also shown that hand gestures are rare across different cultural contexts (Lee et al, 2019). The development of communication mechanisms for automated vehicles may therefore not have to replace explicit communication from the drivers themselves. However, we also found that drivers would frequently turn and look towards the other driver involved in the interaction. In addressing our first research question, we did not find an association between this looking behaviour and the subsequent driving response of the other driver however, unlike the pattern found in pedestrian-driver interactions.

In addressing our second research question however, related to actions associated with taking priority, our observations did suggest that looking towards the other driver was associated with the driver who looked taking priority in the interaction. This may demonstrate the potential importance for drivers of looking towards other drivers, in communicating intentions and resolving interaction ambiguities. Although our observations were unable to confirm with certainty whether eye contact was made when a driver looked towards the other driver, it is possible that eye contact does play a significant role in these low-speed driver-driver interactions. This may be in contrast to interactions with pedestrians, where eye contact may be less frequent (e.g. Sucha, Dostal & Risser, 2017). Without the option of directing gaze towards another driver or making eye contact, automated vehicles may require alternative methods for influencing and resolving issues related to priority in an interaction. They may also need to appropriately interpret the looking behaviour of other road users.

Use of vehicle-based signals by one driver was associated with the other driver being less likely to continue at their same speed without slowing or stopping, and with the other driver giving priority to the signalling driver. This confirms that signals from a vehicle can help resolve interactions, providing justification for ongoing efforts to develop external signal-based communication methods for automated vehicles. These findings related to signal use, taken in combination with our findings about the role of looking towards a vehicle, highlights the importance of visual communication between road users in creating greater clarity during road user interactions. Communication with other road users will be an important task for AVs and has been shown to give other road users greater confidence in interacting with AVs (Merat et al, 2018). Research is needed to understand the most appropriate ways this communication can take place.

5. Conclusion

Understanding interactions between road users, and how they communicate, can help make transport systems safer and support the development of effective communication methods for automated vehicles. This study aimed to identify how different behaviours at the beginning of an interaction were associated with subsequent behaviours and the outcome of the interaction. To address this aim we carried out detailed field observations of pedestrian-driver and driver-driver interactions at a shared space location. This choice of location helps advance our knowledge of road user interactions, as previous research has focused primarily on rule-based or unambiguous road crossing situations. It will be important for the design of AV communication strategies to understand interactions in such shared space settings, given the frequent occurrence of vehicle and pedestrian interactions and the high potential for ambiguities in these interactions. This study contributes towards our understanding in this area.

The observations demonstrated that interaction outcomes are associated with different factors related to the road user, and the looking behaviour of both pedestrians and drivers have an impact on the interaction. In particular, looking towards a driver appears to reduce uncertainty in the interactions and helps confirm which road user will take priority. Although communication between an automated vehicle and a human road user may not be the same as between two human road users, our findings do have implications for the design of automated vehicle communication strategies, for example in demonstrating that current nonverbal communication can reduce uncertainty in interactions. Future research should further consolidate these conclusions and extend them to understand communication and interaction between human road users and AVs. The results suggest there is value in developing our understanding of how nonverbal communication can be used by AVs to reduce uncertainty in interactions with human road users. Such research is needed to develop a consensus and overcome current discord within the literature (e.g. Clamann, Aubert & Cummings, 2015, and Mahadevan et al, 2018). This future research should account for potential cultural differences in how road users communicate during interactions and the implications this may have for AVs operating in different countries and cultural contexts. Our results provide a picture for a UK-based context, further work is needed to see if these results generalise to other contexts. Testing some of the conclusions drawn from our study, for example, that looking towards a driver can increase the smoothness with which interactions transpire, should be validated through experimental designs. This would help overcome some of the limitations associated with the reported observational field study, such as the difficulty in determining whether the driver or vehicle was viewed.

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