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Narrow passage interactions: A UK-based exploratory survey study to identify factors affecting driver decision-making

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ABSTRACT

Narrow passage interactions have received increased attention from academics seeking to create behavioural models of the interaction and those looking to define how autonomous vehicles (AVs) should interact with their human counterparts in a composite road system. Despite this increased attention, many factors remain unexplored in the narrow passage literature, with the literature also encompassing few driving culture contexts. To this end, this study employs an explorative survey to identify additional factors that affect driver decision-making during narrow passage interactions, as well as driver perceptions of different communications in a UK context. The study's 243 participants were presented with a range of different narrow passage scenarios and asked to indicate how likely they were to give way/yield to a vehicle approaching the narrow passage from the opposite direction. In addition, they also completed the Multidimensional Driving Style Inventory to identify their driving styles and asked to identify which signals they look for from their interaction partner during narrow passage interactions, as well as the meaning of those signals. The results of the study show that situational characteristics such as the vehicle type being interacted with, being in a rush and being followed by vehicles alter the likelihood of drivers giving way at narrow passages, whilst a person's driving style can also indicate how likely someone is to give way to another vehicle. These results highlight the factors that are considered by drivers, increasing our understanding of the factors that need to be incorporated in driver behaviour models and in AV development.

1. Introduction

1.1. Cooperative road interactions

Interacting with other road users is a complex endeavour. One aspect that increases the complexity of road interactions is that interacting road users should have a compatible understanding of the space-sharing conflict, a situation in which at least two road users intend to occupy the same space at the same time (Markkula et al., 2020), they are engaged in, in order to prevent collisions (Salmon et al., 2013, 2014; Walker et al., 2011). Whilst formal traffic regulations provide a foundation for drivers to have a compatible understanding of the space-sharing conflict, by helping drivers decide which action(s) they should take (Merten, 1977; Renner & Johansson, 2006), some road interactions require higher levels of self-governance. To build a compatible understanding between road users, these scenarios instead rely on a combination of formal traffic regulations and informal traffic rules that are derived from social convention and are understood by members of society (Cialdini & Trost, 1998). One type of interaction that relies on both formal and

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informal rules of the road are cooperative road interactions.

Cooperative road interactions can be defined as road interactions in which "*two (or more) agents… interfere with the other on goals, resources (and) procedures*" and try to "*manage the interference to facilitate the individual activities and/or the common task*" (Hoc, 2001, p. 515). These interactions have received attention from those looking to model the behaviours of drivers in these interactions (e.g., Troutbeck and Kako (1999) & Aakre and Aakre (2017)) and, more recently, those seeking to understand how autonomous vehicles (AVs) should interact with human-driven vehicles (HDVs) in composite road transport systems (e.g., Stoll, Lanzer and Baumann (2020) & Rettenmaier and Bengler (2021)). This is because driver behaviour models may be unrepresentative of the behaviour of interest without a comprehensive understanding of the factors that affect the behaviour being modelled, which is problematic for both environmental and economic assessments of transport schemes which often use the outputs of these models. Similarly, in the context of AV development, it is vital for AVs to consider and understand all components of cooperative road interactions to ensure that they and potential HDV interactions partners have a compatible understanding of the traffic situation, in order to prevent traffic collisions. Furthermore, this understanding can be also used to ensure that AVs function within the expectations of its human passengers, in order to build trust and increase user acceptance (Beggiato & Krems, 2013; Flemisch et al., 2008; Sun et al., 2020; Wolf, 2015).

Typically, there are thought to be two types of cooperative road interactions: time-pressured dynamic interactions and deadlock interactions (Stoll, Imbsweiler, et al., 2019). Time-pressured dynamic interactions are defined as situations in which one interaction partner has priority and has a limited "time-pressured" opportunity to act to facilitate the other driver's requested manoeuvre, e.g., merging onto a motorway (de Waard et al., 2009). Conversely, deadlock interactions are classified as being lower-speed scenarios in which neither interaction partner can pass or has priority over the other (Stoll, Imbsweiler, et al., 2019), with examples including narrow passage interactions, as well as interactions at T-junctions between three approaching vehicles (Imbsweiler, Ruesch, Weinreuter, et al., 2018). In the case of narrow passage interactions, these are situations in which at least two vehicles travelling in opposite directions meet at a point in the road that has been narrowed (either by design, for the purpose of traffic calming, or due to parked vehicles/other obstructions), such that only one vehicle can pass through the passing point at a time, see Fig. 1. It is, therefore, necessary for the two interaction partners to work together to resolve this conflict and decide who is to go through the narrow passage first.

Despite the increased attention afforded to cooperative road interactions, narrow passage interactions can be considered to be less well researched compared to other cooperative road interactions. With the focus of academic researchers primarily being on how AVs should communicate with other drivers during narrow passage interactions (e.g., Rettenmaier, Albers, et al. (2020)) and the output of this research primarily originating from Germany, few factors have been investigated for their effect on driver decision-making during narrow passage interactions and/or in different cultural settings. This is problematic as the contextual features of interactions have been found to alter the decisions made by drivers, with, for example, the vehicle type of the lead vehicle found to affect car-following behaviour (Brackstone et al., 2009), whilst driving behaviours and their norms vary according to the country and driving culture the behaviour is being investigated in (Factor et al., 2007).

1.2. Aim of current study

The aim of this study is, therefore, to address these limitations by widening the scope of investigation of the factors that affect driver behaviours during narrow passage interactions in the UK. In addition, this study seeks to investigate how drivers communicate with each other during narrow passage interactions in the UK. To this effect, this study aims to utilise an exploratory survey study to identify additional factors that may affect the decisions made by drivers at narrow passages, and the communications drivers seek out throughout these interactions.

2. Literature review

Given the aims of this study, there are two main areas of investigation that must be addressed. First, which factors have been found to affect the decisions made by drivers at narrow passages and which other factors warrant investigation. Second, what are the methods of communication that have been found to be utilised by drivers during narrow passage interactions and therefore need to be investigated in a different cultural context.

2.1. Factors affecting driver decision-making

As per theories of cognition, the actions taken by drivers are dependent on the environmental stimuli that are present at the time (Endsley, 1995; Neisser, 1976). However, whilst different stimuli may exist and render different outcomes, it is important to note that

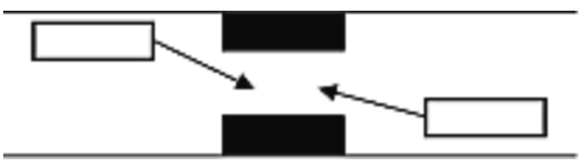

Fig. 1. Schematic of a narrow passage scenario. Neither vehicle has priority nor can pass the other.

the stimuli do not hold some inherent meaning. Instead, any meaning is derived from how a person perceives that information (Neisser, 1976). As such, when investigating factors that affect the decisions made at narrow passages, these factors can be broadly grouped into two categories: factors related to the stimuli present (situational factors) and factors related to how a driver may perceive that information (long-term underlying driver characteristics).

2.1.1. Situational factors

In a review of narrow passage interactions during driving lessons in Germany, Deppermann (2019) argued that the successful resolution of the interaction was dependent on the speeds and distance of the interacting vehicles, the positioning of the obstacles and the passing spaces, as well as the widths of the involved vehicles and the road. Together, Deppermann argued that these variables answer questions critical to resolving narrow passage interactions, including who should give way/yield and how they should do so. It is, however, unclear as to whether the factors highlighted by the driving instructors in the dataset are reflective of those considered by fully licenced drivers or whether they form an idealised/simplified set of rules for negotiating narrow passage interactions for learners.

Despite this potential limitation, the importance of the relative positioning and speeds of the interacting vehicles in relation to the road narrowing has been replicated in other studies. For example, in their observation study Rettenmaier, Requena Witzig and Bengler (2020) found evidence to suggest that an informal *"first-come, first-served"* driving rule exists during narrow passage interactions in Germany. The researchers observed that drivers arriving first at the narrow passage commonly left the narrow passage first, with these drivers often choosing to employ offensive communication strategies (see section 2.2). Complementary to this, the vehicle that arrived second at the narrowing often chose to give way, thus suggesting an informal understanding of the situation. This *"first-come, first-served"* driving rule is further supported by the finding that drivers were more likely to drive first during interactions in which their interaction partner was further away, as specified by the time it would take the opposing vehicle to arrive at the road narrowing (TTC_{OV}) (Miller, Leitner, Kraus, Lee, et al., 2022), as per expectations derived from the gap acceptance literature (Petzoldt, 2014).

In a mixed-methods approach, Miller, Koniakowsky, Kraus & Baumann (2022) utilised a semi-structured interview and simulator study to investigate the differences in the attitudes of drivers when interacting with AVs and HDVs at narrow passages. The semi-structured interview found that drivers expected AVs to adopt more defensive, safety-prioritising actions at narrow passages, in line with previous studies concerning road user perceptions of AVs (Josten et al., 2019; Millard-Ball, 2018; Schieben et al., 2019; Wilbrink et al., 2016). This expectation was further reflected in the behaviours exhibited by participants in the simulator experiment (Miller et al., 2023; Miller, Koniakowsky, et al., 2022). For example, the average speed of participants was higher when encountering an AV compared to a HDV (Miller, Koniakowsky, et al., 2022), and whilst there was no significant effect on the average narrow passage passing time when interacting with AVs and HDVs (Miller et al., 2023), the passing time was shorter when interacting with an AV that gave way (compared to a HDV counterpart that gave way) (Miller, Koniakowsky, et al., 2022). Thus, together, these simulator findings were argued to indicate that drivers behave more offensively when interacting with AVs in narrow passage compared to HDVs, in line with the stated expectations of the two vehicle types. Whilst the authors compared the behaviours produced during interactions with AVs and HDVs, the effect of interacting with vehicles of different types and sizes (e.g., HGVs, SUVs) at narrow passages has not been investigated in the literature (Miller et al., 2023). This is despite research showing that road users recognise and consider the greater cost/risk of colliding with a larger vehicle (Färber, 2016), which, in the context of narrow passage interactions, may lead to more conservative behaviours from drivers interacting with larger vehicles. Indeed, within the cooperative road interaction literature Kondyli & Elefteriadou (2009) noted that the decision of drivers to cooperate with another vehicle during a lane change, and how they chose to do so, was dependent on the size and type of vehicle they were interacting with. As such, in the case of narrow passages, it is hypothesised:

H1: The vehicle type being interacted with influences the likelihood of a driver giving way at a road narrowing.

Beyond investigating how the vehicle type being interacted with may influence the decisions made by drivers at narrow passages, a consideration of the effect of vehicles surrounding the main interaction partners has also been neglected in the literature, with studies tending to design or report on narrow passage scenarios with a single interaction partner travelling in both directions (e.g., Miller, Leitner, Kraus, & Baumann, 2022; Rettenmaier et al., 2021). Given that these simplified scenarios are unlikely to be representative of all narrow passage interactions encountered by drivers and a *"pressuring"* effect has been noted during gap acceptance decisions (Nabaee et al., 2011; Tupper et al., 2011), in that drivers accepted smaller gaps at junctions in which a queue formed behind them, a similar affect may be theorised to exist during narrow passage interactions and therefore warrant further investigation. It is, therefore, hypothesised:

H2: The presence of vehicles behind a driver or behind their interaction partner alters the likelihood of a driver giving way at a narrow passage.

Other than considerations of the vehicles involved during a narrow passage interaction, factors such as the road gradient and the visibility conditions at a road narrowing also present avenues for exploration as to their effect on decisions made during narrow passage interactions. Considering research related to the road gradient, Glennon (1987) noted that accident rates were higher at graded sections when compared to level sections. Indeed, research has further shown that the risk-taking behaviours of drivers varied according to the road gradient (Gerber & Joubert, 2022). Regarding the effect of visibility conditions caused by adverse weather conditions (e.g., fog) and reduced lighting (e.g., at night time), Weng & Meng (2012) found in their analysis that the proportion of risky behaviours produced by drivers increased in poorer visibility conditions. Given that a lack of visibility has been cited as being a potential cause for the infrequent use of some communications at narrow passages (Deppermann, 2019), it may be considered that reduced visibility caused by environmental conditions may also lead to variations of driver behaviours during narrow passage interactions. This study, therefore, hypothesises that:

H3: The road gradient alters the likelihood of a driver giving way at a road narrowing.

H4: Reduced visibility caused by adverse weather conditions/reduced lighting influences the likelihood of a driver giving way at a road narrowing.

Besides situational factors external to the driver, a number of temporary driver characteristics have also been found to alter a driver's perception of a road situation and thus subsequently alter the decisions a driver makes. For example, the mood of a driver has found been to be associated with the driving behaviours they would exhibit, with drivers in a bad mood tending to exhibit more aggressive and risky behaviours (Deffenbacher et al., 2003; Eboli et al., 2017). Similarly, given the role played by the goals of a driver in the representation of a road situation (Baumann & Krems, 2009; Durso et al., 2008; Endsley, 1995; Stanton et al., 2006), drivers in a rush were found to be less likely to cooperate with a requested lane change (Lütteken et al., 2016), as it was theorised that they had assessed that the cost of cooperation was greater (Zimmermann et al., 2018). Given that the cost of cooperation has been shown to affect the likelihood of drivers giving way at narrow passages (Miller et al., 2021), in line with the wider literature (Gerpott et al., 2018; Lütteken et al., 2016; Stoll, Müller, et al., 2019), and the reported ability of these temporary driver characteristics to alter a driver's perception of a road situation, it is hypothesised:

H5: Drivers in a bad mood are less likely to give way to drivers at narrow passages than when they are not in a bad mood.

H6: Drivers in a rush are less likely to give way to drivers at narrow passages than when they are not in a rush.

2.1.2. Long-term underlying driver characteristics

Whilst Miller et al. (2021) noted the influence of the cost of cooperation on decisions made at narrow passages, perhaps the most significant finding related to the differences in the individual perceptions of the drivers. The authors found that drivers that perceived a higher conflict potential (i.e., the difference in interaction partner outcomes), and therefore a higher cost of cooperation, for a given narrow passage interaction were more likely to drive first than those who perceived the conflict potential as being lower (Miller et al., 2021). Similarly, Miller, Leitner, Kraus, Lee, et al. (2022) noted that less risk-averse drivers, measured via the risk propensity scale (Meertens & Lion, 2008), were more likely to drive first at a narrow passage at shorter TTC_{OV} values than drivers who were more risk-averse. Whilst there are questions as to the transferability of these findings to actual driving practices, due to the simplified narrow passage scenarios presented to participants in these video-based studies and the reduced cognitive load of participants resultant from the stipulation that participants were not required to operate the vehicle, these findings highlight that driving decisions during narrow passage interactions vary according to the characteristics and perceptions of the driver. Despite the finding of how driver risk-propensity affects decision-making at narrow passages, the investigation of the association between driving styles and narrow passage decision-making can be considered to be limited. This is because the scope of a person's driving style has been found to extend beyond their risk-propensity (Taubman-Ben-Ari et al., 2004), with produced driving behaviours found to be correlated with different aspects of a person's driving style (Farah et al., 2009). This, therefore, may suggest that other aspects of a person's driving style may also affect decisions made during narrow passage interactions. It is, therefore, hypothesised that:

H7: Multiple aspects of a person's driving style are correlated with the likelihood of a driver giving way at a road narrowing.

Perhaps the factors most widely reported upon in relation to their associations with driving behaviours are the demographic characteristics of drivers. For example, Zhang et al. (2020) noted that commuters consumed less fuel per mile than drivers that drove less frequently at peak hours, whilst female drivers were less fuel efficient than male drivers. Indeed, gender-related differences have been noted across a number of safety statistics (Caparelli-Daquer et al., 2017; Elander et al., 1993; González-Iglesias et al., 2012; Wickens et al., 2008), whilst differences between professional and non-professional drivers in their hazard perception accuracy and reaction times (Caparelli-Daquer et al., 2017) and speed choices (Öz et al., 2010) have also been noted. Considering that the age and driving experience of drivers has been found to be associated with the number of traffic violations a driver is involved in (de Winter & Dodou, 2010), their accident liability (Maycock, 2001; Mayhew et al., 2003) and speed choice (Boyce & Geller, 2002; Elander et al., 1993), it is hypothesised that:

H8: There are gender-related differences in the likelihood of giving way at narrow passages.

H9: There are age-related differences in the likelihood of giving way at a road narrowing.

H10: There are experience-related differences in the likelihood of giving way at narrow passages.

H11: The number of times a driver drives per week alters their likelihood of giving way at a road narrowing.

H12: There are differences in the likelihood of giving way at a narrow passage between drivers that hold an additional professional driving licence and those that don't.

2.2. Methods of communication

Using an observation protocol method (Dietrich et al., 2018) to record narrow passage interactions in Germany, Rettenmaier et al. (2020) replicated the results of previous studies (Imbsweiler et al., 2016), and found that explicit communications, communications that do not alter a vehicle's dynamics or trajectory (e.g. flashing of headlights, hand gestures) (Bengler et al., 2020; Markkula et al., 2020; Miller, Koniakowsky, et al., 2022), were seldom used. This finding was made contrary to previous suggestions of the vitality of explicit signals in ensuring successful narrow passages interactions (Imbsweiler, Stoll, et al., 2018) and the preference held by participants for explicit communications during interactions with AVs (Miller et al., 2023; Rettenmaier, Albers, et al., 2020). Indeed, explicit signals had previously been found to be associated with communicating intent to give way at the narrow passage (Imbsweiler, Ruesch, Heine, et al., 2018), such that it had been argued that flashing headlights in combination with decelerating is the clearest way of indicating the intention to give way at a narrow passage (Imbsweiler, Palyafári, et al., 2017). Like Deppermann (2019), Rettenmaier et al. (2020) argued that the limited use of explicit communications during narrow passage interactions may be caused by limited visibility of the interaction partner. In addition the authors further argued that, given that explicit communications have been hypothesised to help resolve situations that require further negotiation/clarification (Dey & Terken, 2017; Lee et al., 2020), the lack of produced explicit communications may be associated with unambiguous narrow passage interactions, resultant of clear priority as regulated by the *"first-come, first-served"* informal rule or a clear understanding of the intentions of the interaction partners via their implicit communications, communications related to vehicle dynamics and trajectory (Bengler et al., 2020; Markkula et al., 2020; Miller, Koniakowsky, et al., 2022).

Further exploring implicit communications during narrow passage interactions, Rettenmaier, Albers & Bengler (2020), Rettenmaier, Dinkel & Bengler (2021) and Rettenmaier & Bengler (2021) highlighted the importance of lateral positioning when communicating in a series of simulator experiments. 'Pulling in' was found to be perceived by drivers as giving way, whilst the inverse was true when a driver remained central on the road (Rettenmaier, Albers, et al., 2020). Indeed, the authors found that the use of lateral offsets resulted in safer and more efficient narrow passage interactions (Rettenmaier et al., 2021; Rettenmaier & Bengler, 2021), which was argued to be due to the increased saliency in communication when also using lateral offsets, as opposed to just longitudinal positioning, due to a greater change in driver visual angle (Hills, 1980). This finding was replicated by Miller, Leitner, Kraus & Baumann (2022), who also argued that the use of lateral positioning was interpretationally advantageous during narrow passage interactions, as lateral deviations are more closely associated to the intent of the driver, as it is part of the manoeuvre that is being carried out (Dey et al., 2020). Longitudinal movements, on the other hand, whilst associated with predicting the intent of a driver at a narrow passage, require additional inferences as to the underlying intention of the opposing driver, using derived changes in TTC_{OV}.

Whilst the narrow passage literature is largely consistent regarding the methods in which drivers communicate with one another at a road narrowing, the origins of the literature are potentially limiting, with the published literature originating primarily from Germany. The pertinence of considering the origin of the literature arises from findings that different countries have different driving cultures and therefore potentially differing informal and formal rules and interpretations of similar driving situations (Edensor, 2004; Factor et al., 2007). This may, therefore, mean that the communications found during narrow passage interactions in the current literature, and indeed the factors thus far found to affect driver decision-making, may not necessarily be transferable to other countries and their driving cultures. For example, whilst the flashing of headlights has been argued to be a key indicator of an intent to give way at narrow passages and the use of eye contact is actively encouraged in Germany (Tennant et al., 2015), in the UK the Highway Code warns against unclear signalling (Tennant et al., 2021), specifying that drivers should not flash their lights except to let other road users know that they are there (Department for Transport, 2019, Rule 110). It is, therefore, vital to investigate the communications produced during narrow passage interactions in other cultural contexts, including in a UK setting. As such, this study seeks to answer:

RQ1: Which communications are used by drivers to ascertain that their interaction partner is giving way at a road narrowing in the UK.

RQ2: Which communications are used by drivers to ascertain that their interaction partner is passing through first at a road narrowing in the UK.

3. Method

3.1. Survey design

In order to investigate the research questions and hypotheses posed, an exploratory survey study was conducted. As part of a larger survey study investigating driver decision-making during cooperative road interactions in the UK, participants were asked to provide demographic data. The collected demographic data, as per hypotheses 8–12, included the age, gender, and driving experience of the participants, their holding of additional professional driving licences (e.g., the Driver Certificate of Professional Competence), as well as how often they drove in a typical week. To investigate the effect of a driver's driving style on their decision-making during narrow passage interactions, participants were asked to complete the Multidimensional Driving Style Inventory (MDSI) questionnaire (Taubman-Ben-Ari et al., 2004). The MDSI consists of 44 questions that ask participants, on a 6-point Likert scale, how often they think/do a range of actions whilst driving, the answers of which are used to calculate factor scores for different driving styles. The MDSI was chosen due to its ability to capture the complex and multidimensional nature of a person's driving style, as well as its

Table 1
Factors to be investigated for their affect on driver decision-making at narrow passages in this study grouped by factor category.

Factor Category	Factor
Situational Factors	Vehicle Type of Interaction Partner Presence of Interaction Vehicles beyond Lead Interaction Partners Road Gradient Road Visibility caused by adverse weather conditions/lighting Driver Mood Driver Time Pressure
Long-term Underlying Driver Characteristics	Driving Style Gender Age Driving Experience Driving Frequency Professional Driving Licence

validation against both simulator study (Farah et al., 2009) and instrumented vehicle study data (Taubman-Ben-Ari et al., 2016).

In order to investigate the different factors hypothesised to affect driver decision-making at narrow passages in Table 1, participants were presented with a schematic of a narrow passage interaction, see Fig. 2, and given a text-based description of the contextual features of a base-case scenario. In this description, participants were told that they were in a **good mood** and were going for a **leisurely drive** on a **level road** during a **clear day**. They were also told that whilst travelling along a road at 25 miles per hour (mph) they encountered a narrowing narrowed on both sides, as well as a **family car** travelling in the opposite direction at 25mph, with **no other vehicles nearby**. Given that only one vehicle can pass through the narrowing at a time, participants were asked to indicate how likely they were to give way to the family vehicle in this base case scenario using a 6-point Likert Scale (1 = definitely not, 2 = very unlikely, 3 = unlikely, 4 = likely, 5 = very likely, 6 = definitely). Like other studies investigating driver behaviours in cooperative road interactions (Miller et al., 2021; Stoll et al., 2020), the term "cooperation" was avoided in the description of the scenario to minimise the inducement of biases related to social desirability.

The participants were then given text-based descriptions of altered narrow passage interactions. The altered scenarios only had one factor manipulated from the base case scenario, and participants were told to indicate how likely they were to give way in the altered scenario given the manipulated factor, **with everything else being equal** (e.g., *"with everything else being equal, how likely are you to give way to the other vehicle when you are in a rush"*). This was, again, indicated on the same 6-point Likert scale as was used in the base case scenario, thus allowing for a direct comparison of the likelihood of giving way between the altered scenarios and the base case scenario. In addition to the altered scenarios, the participants were also asked to rank a range of vehicle types (e.g., lorries, buses, SUVs) according to how likely they were to give way to that vehicle during a given narrow passage interaction.

In order to understand how drivers communicate with each other during narrow passage interactions in the UK, the survey presented participants with a range of different communication types that had previously been shown to be used by drivers during narrow passage interactions in other cultural contexts. Participants were then asked, in two separate questions, to indicate, by ticking, the methods of communication they interpreted as meaning that their interaction partner intended to give way or that they intended to pass through first at a narrowing. Participants were also given an opportunity to provide any additional comments they had regarding additional means of communication or indeed of narrow passage interactions generally.

3.2. Study procedure

Participants completed the survey online on the iSurvey platform, as part of a larger study investigating factors affecting driving behaviours. Participants were initially approached with a brief description of the study and the study's URL via social media groups, driving forums and the Universities Transport Study Group (UTSG) mailing list between December 2020 and February 2021. Monitoring of participant rates then led to additional targeting of forums that consisted of under-represented demographics (e.g., middle-aged females). The only inclusion criteria placed on participation was that prospective participants had to be above the age of 18 and be in possession of a full UK driving licence, to limit the effect of other driving cultures on the findings of the study. Interested participants that met the inclusion criteria then reviewed an information sheet, before giving consent. Demographic data was then collected from participants, before questions regarding the investigated driving behaviours and narrow passage interactions were asked. The MDSI section of the survey was conducted at the end of the survey. The study was approved by the University's Ethics Committee (study ethics ID: 62309).

3.3. Participants

A total of 243 participants completed the narrow passage section of the survey, see Fig. 3. Of the 243 participants that completed the narrow passage portion of the survey, 72 % of participants identified as male, 28 % identified as female, with one participant not identifying as male or female. The largest age group was 50–59 years (26 %), whilst the smallest age group was the 70 + age group (3 %). 60 % of participants stated that they had held their licence for more than 15 years, whilst nearly half (49 %) of the participants stated that they typically drove daily. Lastly, 33 % of participants reported that they held an additional professional driving licence.

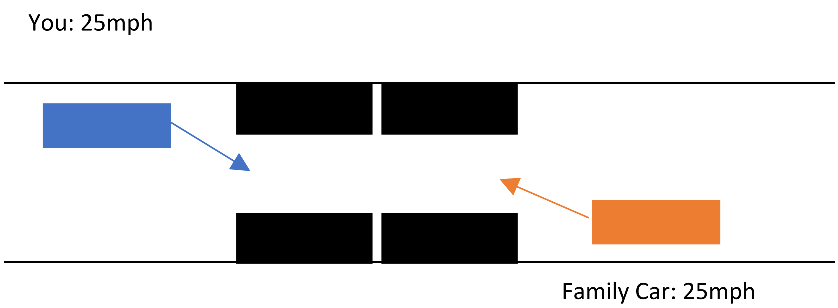

Fig. 2. Schematic of the base case narrow passage scenario given to participants in the study.

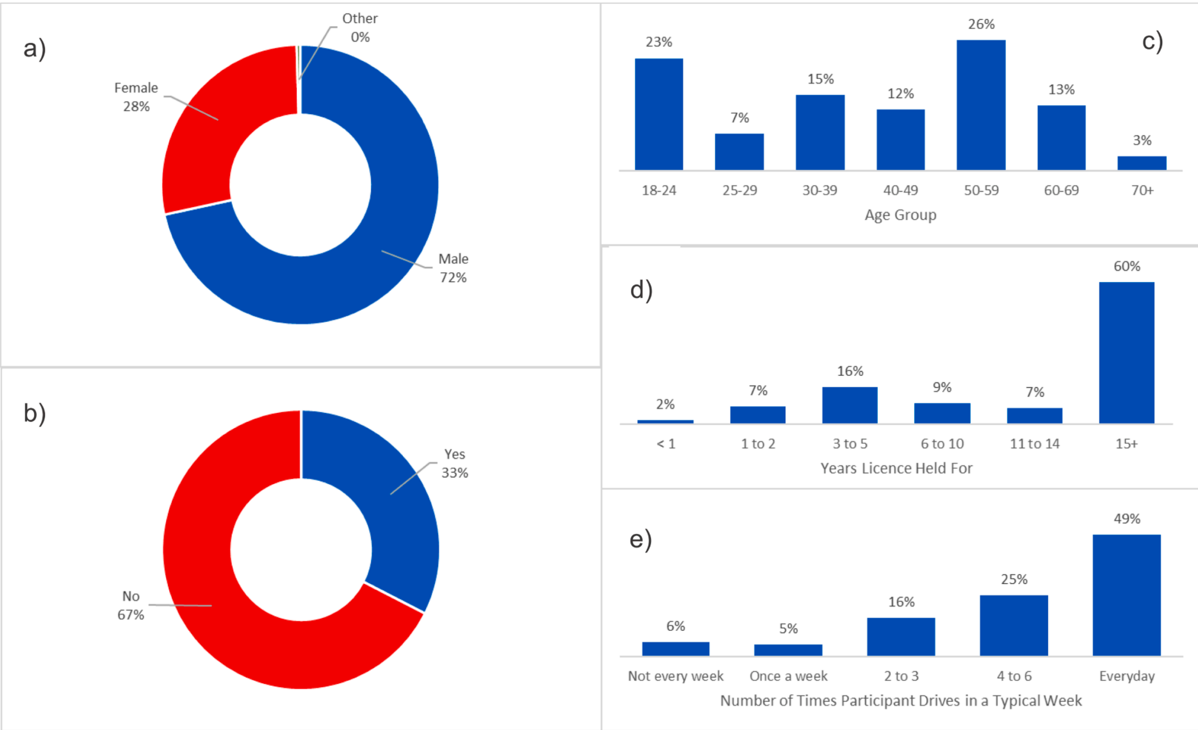

Fig. 3. Demographic data: a) Gender Breakdown, b) Breakdown of those with and without an additional professional driving licence, c) Breakdown of the age groupings of the sample, d) The years participants had held their licences for, e) Number of times participants drive in a typical week.

3.4. Data analysis

All statistical analyses were conducted using the software package IBM SPSS Statistics version 28. The exploratory factor analysis conducted on the items of the MDSI was conducted according to the analysis framework as outlined in Youssef et al. (2023). The analysis of the situational factors investigated in this study were initially analysed using Friedman's ANOVA. Friedman's ANOVA, and non-parametric tests generally, was utilised in this study given that the ordinal nature of the data collected in this study may result in violations of the assumptions of parametric tests that may have instead been used to analyse the data (Jamieson, 2004). Subsequent post-hoc tests using Wilcoxon Signed Rank tests were used following statistically significant findings from Friedman's ANOVA, with Bonferroni corrections applied, to calculate any effect sizes. To investigate the differences in the rankings of the vehicle types, a

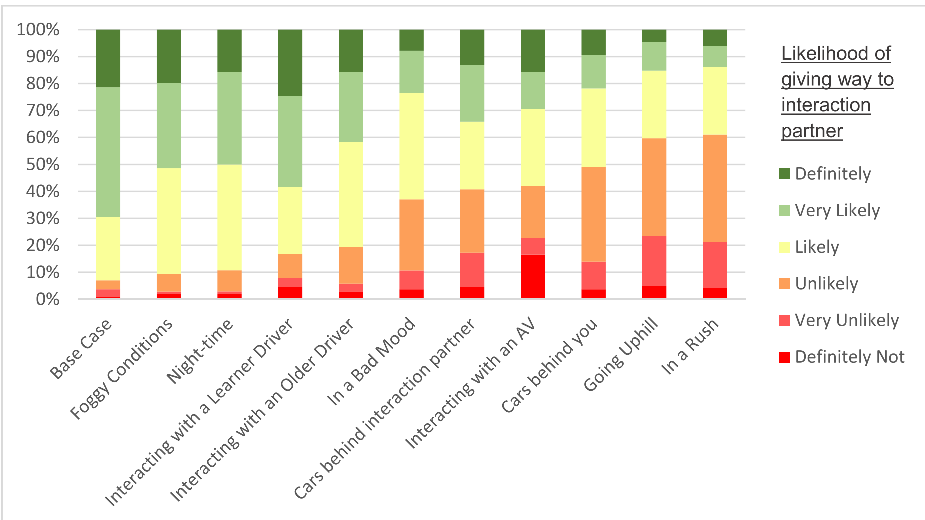

Fig. 4. The proportion of responses given to each narrow passage scenario.

repeated measures ANOVA was conducted. Prior to completing the test, Mauchly's test was used to test the assumption of sphericity, with the Greenhouse-Geisser correction applied when the estimate of sphericity was less than 0.75 (Field, 2015; Girden, 1992). Subsequent post-hoc tests with Bonferroni corrections were used to make pairwise comparisons between the different vehicle types. To test the correlation between different aspects of a person's driving style and their likelihood of giving way, Spearman's rank correlation test was used. Mann-Whitney U tests were used to investigate the effects of gender and additional professional licences on the likelihood of giving way at a narrowing, with further Chi-squared and Cramer's V tests used to test for the association between gender and giving way. In place of one-way independent ANOVA tests, non-parametric Kruskal-Wallis tests were used to assess differences in the likelihood of giving way between different age, experience and driving frequency groups. Jonckheere–Terpstra tests were then used following statistical significant findings from the Kruskal-Wallis tests to investigate trends across the different groupings (Field, 2015). Lastly, a McNemar test was used to assess whether there was a statistically significant difference in the associations of each communication method and giving way or passing through first at a road narrowing.

4. Results

4.1. Situational factors

Investigating how the different situational factors affect the likelihood of drivers giving way during a narrow passage interaction, Fig. 4 presents a breakdown of the answers given by the participants for each of the tested scenarios.

To test whether the responses of the participants significantly changed across the scenarios Friedman's ANOVA was utilised and revealed significant differences in the likelihood of giving way across the narrow passage scenarios $\chi^2(10) = 669.99$, $p < .001$. Additional Wilcoxon tests revealed that, when compared to the base case narrow passage scenario, all scenarios reported statistically significant differences, see Table 2. For example, participants reported that they were statistically significantly less likely to give way when in a rush (Median = 3.00) compared to the base case scenario, in which participants were not in a rush, (Median = 5.00), T = 744.50, $p < .001$, r = -0.530. The results, therefore, not only indicate that the situational characteristics lead to differences to the giving way likelihood of drivers during narrow passage interactions but also indicates that these effect are medium-sized (<0.5) in many scenarios and small-to-medium (0.2–0.5) in all cases bar when interacting with a learner driver and in foggy conditions, according to the benchmarks proposed by Cohen (1988).

Considering how the likelihood of participants giving way changes according to the vehicle type they are interacting with at a narrow passage, see Fig. 5, a repeated-measures ANOVA revealed significant differences in the average ranking of the vehicle types that drivers would let pass through a narrow passage first (F(7.52, 6026.54) = 53.79, $p < .001$)). Subsequent posthoc tests revealed three broad groupings of vehicles that had similar rankings with each other ($p > 0.05$) but were dissimilar to most of the vehicle types in the other groups ($p < 0.05$). The first group, consisting of the vehicle types that the participants reported they would be most likely to give way to during a narrow passage interaction, compromised learner vehicles, buses, and lorries. On the other hand, sports cars, SUVs, AVs, and taxis were all ranked as being the vehicle types that participants were least likely to let pass through first.

Lastly, whilst not explicitly asked, participants made additional comments regarding the existence of a *"first-come, first-served"* driving rule at narrow passages, noting that the relative distances of drivers to the passing point of the narrow passage dictates who should go first (e.g., *"The car that is closest to the obstruction goes first"* – PI 4333728*)*.

4.2. Long-term underlying driver characteristics

Spearman's rank correlation test was used to explore the correlations between the likelihood of a driver giving way to their interaction partner during the base case narrow passage scenario and their driving style. The test revealed that risk-taking (r(160) = -0.342, $p < .001$), angry (r(160) = -0.192, $p = .015$) and high-velocity (r(160) = -0.195, $p = .013$) driving style scores were all statistically significantly negatively correlated with the likelihood of giving way during the base case narrow passage interaction scenario, whilst careful driving style scores (r(160) = 0.362, $p < .001$) were found to be statistically significantly positively correlated with a person's likelihood of giving way in the base scenario, see Table 3.

These statistically significant correlations were also present throughout the altered scenarios. The risk-taking, angry and high-velocity driving styles were all negatively associated with the likelihood of giving way, (e.g., the angry (r(160) = -0.353, $p < .001$), high-velocity (r(160) = -0.362, $p < .001$) and risk-taking (r(160) = -0.212, $p = .007$) driving styles were all significantly negatively correlated with giving way at narrow passages when in a rush), whilst the distress-reduction and careful driving styles were positively

Table 2
Results from Wilcoxon Signed-Rank Tests comparing the altered scenarios against the base scenario, with the calculated effect sizes.

Scenario	Bad Mood	In a Rush	Foggy Conditions	Night-time	Cars Behind Interaction Partner	Cars Behind You	Going Uphill	Interacting with a Learner Driver	Interacting with an Older Driver	Interacting with an AV
Median	4.00	3.00	5.00	4.50	4.00	4.00	3.00	5.00	4.00	4.00
T	934.50	744.50	1867.00	1641.50	1528.00	761.00	538.00	3126.00	1432.50	1280.00
p	< 0.001	< 0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.012	< 0.001	< 0.001
Effect Size	−0.464	−0.530	−0.177	−0.224	−0.398	−0.476	−0.530	−0.147	−0.317	−0.421

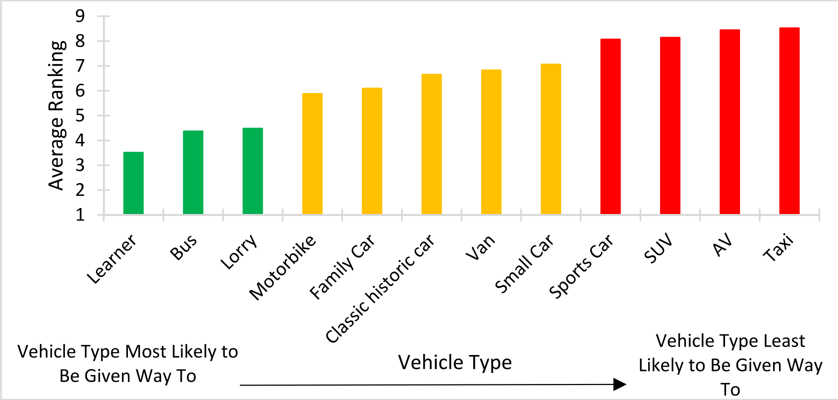

Fig. 5. The average ranking of different vehicle types based on the likelihood of giving way to them at a narrow passage. The different colours indicate the groupings of the vehicle types with statistically similar rankings.

Table 3
Spearman's Rank correlation coefficients (N = 160) between the identified MDSI driving styles and the different narrow passage driving scenarios.

		Risk-Taking	Anxious	Angry	Careful	High-Velocity ***	Distress-reduction
Base Case	Correlation Coefficient	-0.342**	-0.059	-0.192*	0.362**	0.195*	0.138
In a Bad Mood	Correlation Coefficient	-0.314**	0.014	-0.317**	0.314**	0.317**	0.136
In a Rush	Correlation Coefficient	-0.212**	-0.030	-0.353**	0.104	0.362**	0.052
Foggy Conditions	Correlation Coefficient	-0.312**	0.070	-0.250**	0.399**	0.230**	0.021
Night-time	Correlation Coefficient	-0.290**	0.045	-0.237**	0.399**	0.232**	0.087
Cars Behind Interaction Partner	Correlation Coefficient	-0.169*	-0.177*	-0.252**	0.131	0.238**	0.112
Cars Behind You	Correlation Coefficient	-0.127	-0.217**	-0.064	0.191*	0.169*	0.132
Going Uphill	Correlation Coefficient	-0.192*	-0.130	-0.073	0.159*	0.080	0.126
Interacting with a Learner Driver	Correlation Coefficient	-0.261**	-0.035	-0.176*	0.322**	0.194*	0.129
Interacting with an Older Driver	Correlation Coefficient	-0.375**	-0.132	-0.244**	0.356**	0.358**	0.228**
Interacting with an AV	Correlation Coefficient	-0.235**	-0.003	-0.212**	0.160*	0.252**	0.036

*** Indicated positive correlations with the high-velocity driving style indicate a negative relationship with high-velocity driving style scores due to the negative loading of all items in the driving style
**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

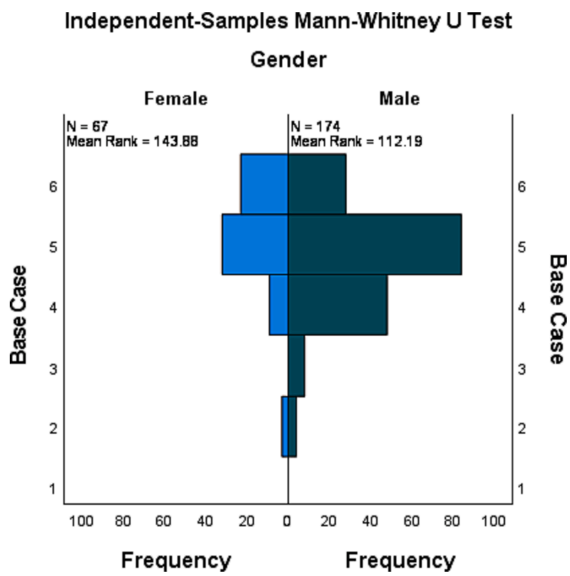

Fig. 6. Distribution of scores between males and females for the base case scenario (taken from SPSS output).

correlated with the likelihood of giving way in all scenarios (e.g., the careful driving style was statistically significantly positively correlated with giving way in foggy conditions ($r(160) = 0.399$, $p < .001$)). Scores for the anxious driving style fluctuated between having negative and positive associations with the likelihood of giving way across the different scenarios, (e.g., anxious driving style scores were statistically significantly negatively correlated with giving way in narrow passage interactions where the participant was being followed by a stream of vehicles ($r(160) = -0.217$, $p = .006$)).

Using gender to characterise drivers and their likelihood of giving way to their interaction partner in the narrow passage base-case scenario, Mann-Whitney U tests revealed that female drivers (Mean Rank = 143.88) were statistically significantly more likely to give way ($U = 7362.00$, $z = 3.398$, $p < .001$) than their male counterparts (Mean Rank = 112.19), see Fig. 6. Further chi-squared tests showed a significant association between gender and those who would "definitely give way" ($\chi(1) = 9.643$, $p = .003$). These findings were confirmed by a Cramer's V test, which revealed a highly significant ($p = .002$) association of 0.20, with females being significantly associated with "definitely giving way" more than expected, with the opposite true for men. Further statistically significant gender differences in the likelihood of giving way were found, with females (Mean Rank = 135.48) more likely to give way than males (Mean Rank = 115.31) when it was foggy ($U = 6866.50$, $z = 2.131$, $p = .033$), when they interacted with a learner vehicle (Female: Mean Rank = 140.30; Male: Mean Rank = 113.41; $U = 7194.50$, $z = 2.795$, $p = .005$), older drivers (Female: Mean Rank = 140.64; Males: Mean Rank = 112.54; $U = 7217.50$, $z = 2.953$, $p = .003$), and AVs (Female: Mean Rank = 143.46; Males: Mean Rank = 111.05; $U = 7257.50$, $z = 3.311$, $p < .001$) and when it was night-time (Female: Mean Rank = 139.01; Males: Mean Rank = 113.18; $U = 7106.50$, $z = 2.746$, $p = .006$). Chi-squared tests further showed a significant association with gender and "definitely giving way" at night at narrow passages ($\chi(1) = 6.683$, $p = .010$), with Cramer's V test revealing a statistically significant ($p = .010$) association of 0.167. In this case, females were again associated with being more likely to "definitely give way". Similarly, Chi-squared tests also revealed an association with definitely giving way when there was a stream of cars behind the interaction partner and gender, $\chi(1) = 7.147$, $p = .008$, with Cramer's V also revealing a highly significant ($p = .008$) association of 0.172. In this case, females were associated with being more likely to "definitely give way" than males.

Mann-Whitney U-tests revealed no statistically significant differences in the likelihood of giving way for drivers with and without an additional professional driving licence during narrow passage interactions, whilst few statistically significant differences were reported from Kruskal-Wallis tests across the different narrow passage scenarios between the different age, experience and driving frequency groups. For example, Kruskal-Wallis tests revealed that the likelihood of giving way when in a rush was statistically significantly affected by a person's age $H(6) = 22.394$, $p = .001$. A Jonckheere-Terpstra test further revealed that as a participant's age increased their likelihood of giving way to their interaction partner when in a rush also increased, $J = 14394.00$, $z = 4.621$, $p < .001$, $r = 0.296$. Similarly, Kruskal-Wallis tests revealed that the time a person had held their driving licence for affected their likelihood of giving way to their interaction partner when in a rush $H(5) = 16.243$, $p = .006$, with the Jonckheere–Terpstra test revealing that drivers who had held their driving licence for longer were more likely to give way $J = 11001.00$, $z = 3.859$, $p < .001$, $r = 0.247$. Kruskal-Wallis tests also revealed statistically significant differences in the giving way likelihood of drivers when interacting at a narrow passage in foggy conditions according to how often they drove in a typical week $H(4) = 14.149$, $p = .007$, with the Jonckheere–Terpstra test revealing that drivers who drove more in a typical week were less likely to give way $J = 8131.50$, $z = -3.168$, $p = .002$, $r = -0.203$. No

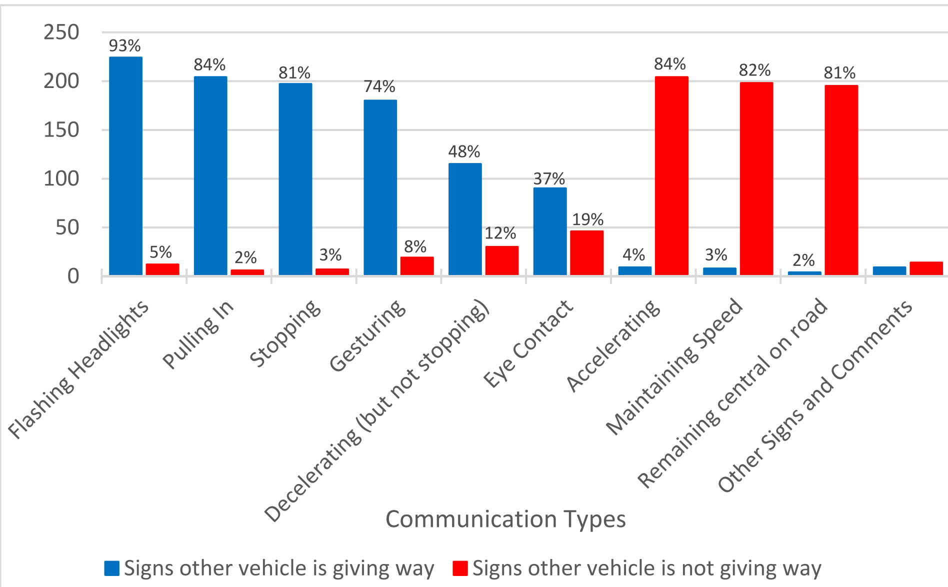

Fig. 7. The signs that the participants reported looking for from their interaction partner that they are giving way (blue) or not giving way (red) during a narrow passage interaction. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

other statistically significant findings related to age, driving experience, and driving frequency were found by Kruskal-Wallis tests.

4.3. Methods of communication

Fig. 7 shows the number and proportion of participants that look for the different communicative signs from their interaction partner at a narrow passage, as well as how they would interpret these signs.

The sign most commonly perceived by participants as communicating an intent to give way was the flashing of headlights (93 %), whilst pulling in (84 %), stopping (81 %) and hand gestures (74 %) were also commonly perceived as communications that an interaction partner intends to give way. Conversely, the signs most commonly perceived as communicating an intent to pass though first were accelerating (84 %), maintaining speed (82 %) and remaining central on the road (81 %). To evaluate whether the perceptions of the different communication methods were significantly associated with giving way or passing through first, McNemar's test was utilised, see Table 4. As shown in Table 4, the null hypothesis was rejected for every communication method ($p < .001$), thus highlighting that each communication was statistically significantly associated with the intent that was perceived by the greater number of participants.

Focusing on the additional comments made, participants also revealed that the use of car indicators consistent with the lateral movement of a vehicle was a means of deciphering the intent of an interaction partner (e.g., *"Quick flash of the near side turn signal"* – PI 4312075), whilst other participants elaborated that a lack of eye contact was perceived as a sign that a driver was not going to give way (e.g., *"Not making eye contact at any stage"* – PI 4334634).

5. Discussion

5.1. Situational factors

The finding that all the investigated situational factors led to statistically significant differences in the likelihood of giving way at a road narrowing, thus confirming hypotheses 1–6, can be argued to be in line with expectations. For example, it has been previously highlighted that the risk profiles of drivers varies according to the road gradient (Gerber & Joubert, 2022) which, therefore, may support the notion that the likelihood of giving way at a narrowing when travelling uphill may differ from that when travelling on a level road. When it is also considered that the UK Highway Code states that drivers should give way to road users travelling uphill on country roads (Department for Transport, 2019, Rule 155), a possible explanation for drivers being less likely to give way when travelling uphill at a narrow passage is provided. Similarly, the finding that drivers in a rush were less likely to give way at a narrow passage is in line with findings from the cooperative lane change literature, in which it was hypothesised that drivers in a rush may have less motivation to give way due to a perceived higher cost of cooperation (Lütteken et al., 2016; Miller et al., 2021).

The results also show the importance of the presence of surrounding vehicles on driver decision-making at narrow passages, with vehicles behind either interaction partner leading to the participants reporting that they would be less likely to give way. One theory for the reduction in the likelihood of giving way when there are vehicles following the opposing vehicle may be linked to an increased cost of cooperation of giving way, due to a longer perceived waiting time of having to wait for more vehicles to pass through the narrow passage first. On the other hand, a *"pressuring"* effect caused by follower vehicles, similar to that noted in the gap acceptance literature (Nabaee et al., 2011; Tupper et al., 2011), may be hypothesized to cause drivers to be more aggressive at narrow passages when being followed, and therefore less likely to give way.

Interestingly, the survey found that poor lighting conditions (e.g., fog and darkness from night-time) also led to a decrease in the likelihood of giving way at a narrow passage across the sample population. A possible explanation for these findings may be related to previous findings that drivers prefer to go through narrow passages first (Miller et al., 2021) and were more confident in doing so (Imbsweiler, Palyafári, et al., 2017). Given that drivers have a tendency to rate their driving skills as being superior to other drivers (Svenson, 1981), it may be that taking the initiative at a road narrowing during low visibility conditions is preferential to drivers, as communicating that intent may be less unambiguous, and thus may add greater certainty to the interaction, resulting in a quicker resolution of the interaction.

The statistically significant differences in the likelihood of giving way to different vehicle types suggests that drivers do consider the type of vehicle they are interacting with during narrow passage interactions, perhaps due to the activation of different mental models

Table 4
McNemar's Test results for Communication Methods based on participant interpretations of the meaning of that communication.

Communication Method	N	Chi-Square (χ^2)	p
Acceleration	245	187.24	<0.001
Maintaining Speed	245	184.13	<0.001
Deceleration but not Stopping	245	54.70	<0.001
Stopping	245	186.05	<0.001
Stopping & Flashing Lights	245	208.04	<0.001
Gesturing	245	153.29	<0.001
The vehicle has pulled in	245	194.05	<0.001
The vehicle is central on the road	245	189.01	<0.001
Eye Contact	245	28.02	<0.001

when presented with different vehicle types. The activation of these different mental models helps road users interpret the information available to them, thus creating expectations of that information that informs any decisions a driver produces in a top-down process (Plant & Stanton, 2016). Considering the finding that participants are, at least hypothetically, less likely to give way when interacting with an autonomous vehicle (AV), this may be a reflection of participant expectations that AVs will have a more conservative driving style to ensure the safety of road users and therefore may be more likely to give way than a typical human driver, in line with previous AV-related findings (Hulse et al., 2018; Josten et al., 2019; Miller, Koniakowsky, et al., 2022). Similarly, the low rankings of the other vehicle types (SUVs, taxis, sports cars) may suggest negative attitudes/preconceptions towards these vehicle types from participants (e.g., *"What car they are driving, certain car brands attract bad drivers"* – PI 4312048), which may mean that they are less willing to give way to these vehicle types. On the other hand, learner vehicles, buses and lorries were all ranked as being the vehicle types that participants were most likely to let pass through first. The inclusion of buses and lorries in this group may be linked to the large size of these vehicles and their associated manoeuvrability. Compared to smaller vehicle types, these vehicles may find it harder to find a place to stop to allow their interaction partner to pass through first, which other drivers may consider during the interaction. In addition, drivers may also assess that the risk of passing through a narrow passage first is greater when interacting with a larger vehicle due to the potentially greater severity of a crash if both vehicles decide not to give way to the other (Färber, 2016). Manoeuvrability may also be a consideration when interacting with learner vehicles (the vehicle type drivers reported as being the type they would most likely give way to), with drivers perhaps opting to provide additional time and space to learners by giving way to make up for their lack of control/experience.

Whilst not investigated in this study, comments regarding the previously hypothesised *"first-come, first-served"* rule (Rettenmaier, Requena Witzig, et al., 2020) as a method of deciphering priority were made. It is unclear, however, how this rule interacts with other factors (e.g., the driver arriving second is in a rush) and communications (e.g., are drivers who are closer more likely to accelerate or maintain their speed), as the survey did not investigate multiple factors simultaneously.

Considering the results together, this study extends the current literature by showing that the decision-making of drivers may be altered by the motivations of the drivers as well as the specific external characteristics of the interaction. For the development of AVs, an understanding of how these factors may influence the expectations/preferred behaviours of drivers at narrow passages is vital, given that the compatibility of an AVs decision-making with that of how drivers currently make decisions has been found to be key to developing user acceptance of AVs (Nastjuk et al., 2020). For example, given that drivers were found to be less willing to give way at a road narrowing whilst travelling uphill, it may be that this preference is reflected in the development of AVs, with AVs explicitly considering the gradient of the road in its decision-making. In the context of developing a traffic simulator driver behaviour model for narrow passage interactions, the findings regarding the importance of vehicle types involved in an interaction and the influence of surrounding vehicles in driver decisions to give way during a narrow passage interaction are particularly pertinent. Both factors could be easily included in these driver behaviour models as explanatory variables, as their "values" are more easily obtained from the video footage that is used to calibrate and validate these behavioural models, when compared to information related to the mental state of a driver or even the road gradient (Gerber & Joubert, 2022).

5.2. Long-term underlying driver characteristics

This study found that different aspects of a person's driving style were statistically significantly correlated with their decision to give way during different narrow passage interactions, thus confirming the seventh hypothesis of the study. These results, therefore, not only validate previous findings regarding the risk-propensity of drivers and their decision-making at narrow passages (Miller, Leitner, Kraus, Lee, et al., 2022), but are also in line with the definitions of the different driving styles (see Taubman-Ben-Ari et al. (2004)) and thus may be considered as being expected. For example, more anxious drivers are likely to carry out actions that result in the least amount of personal stress, which will vary as the situation varies. Alternatively, those with higher angry, risk-taking and high-velocity driving style scores are more likely to engage in antisocial and unsafe behaviours that minimise their delays and thus when in a rush may be less likely to want to give way to other drivers during a narrow passage interaction. The correlations associated with the risky and angry driving styles also explains why drivers in a bad mood may be less likely to give way to an interaction partner at a narrow passage (compared to when they are in a good mood), as being in a bad mood has been found to be associated with more risky and angry driving (Deffenbacher et al., 2003; Eboli et al., 2017). Lastly, when considering that the careful and distress-reduction driving styles are linked to considered and relaxed driving, drivers who score more highly for these driving styles may be thought to be more likely to give way to an interaction partner during a narrow passage interaction.

The study was able to find gender-related differences in the likelihood of giving way during narrow passage interactions. One possible explanation for these findings may lie in findings that females drivers score more highly for the careful driving style than men (Taubman-Ben-Ari & Yehiel, 2012; Youssef et al., 2023), which in turn was found to be positively correlated with giving way in each of the scenarios. The findings regarding additional professional driving licences suggest that whilst those with an additional professional licence are trained to be more competent drivers, their underlying motivations in their decision-making during narrow passage interactions are not changed. The study also found few statistically significant findings between the age, experience or driving frequency of a driver and their likelihood of giving way at a narrow passage across the scenarios. The lack of findings for these demographics may be due to a lack of representation of some demographic groups, resulting in high variations within some of the groups. As such, a larger sample size may be needed to find whether any significant differences exist between different age, experience and driving frequency groups.

Considering the findings altogether, the results illustrate the importance of considering a person's driving style when predicting the actions they are likely to take during a narrow passage interaction and suggests that a person's driving style may be the most robust demographic indicator of whether they are likely to give way during a narrow passage interaction. These results, therefore, highlight the ability of the MDSI to produce driving styles that are seemingly representative of driving behaviours, thereby providing further validation for the measure, but more importantly, in the context of producing behavioural models, the decisions of drivers at narrow passages can be interpreted to remain consistent with other driving behaviours exhibited, due to other MDSI findings (e.g., speed choice (Hooft van Huysduynen et al., 2018) and gap-acceptance decisions (Farah et al., 2009)). This, therefore, suggests that a single set of driving style factors may be applicable in traffic behaviour models to describe the give way decisions of drivers during narrow passage interactions and other driving situations (e.g., lane changing), thereby ensuring that decision-making is not homogenous in these models and is consistent amongst the different driving behaviours.

5.3. Methods of communication

In answer to the communication research questions posed in this study, it has been shown that both implicit and explicit communications are used by drivers in the UK when deciphering the intention of their interaction partner, with the interpretations of the different communication types statistically significantly associated with either giving way or passing through first in all instances.

Focusing on explicit signals, these communication types were generally perceived as signs that an opposing vehicle is willing to give way at the narrow passage, in agreement with the previous literature (e.g., Imbsweiler, Ruesch, Heine, et al. (2018)). Indeed, the finding that flashing headlights was the sign most looked for/interpreted as a sign that an interaction partner was giving way is not only in line with the findings of previous studies (Imbsweiler, Palyafári, et al., 2017; Imbsweiler, Stoll, et al., 2018), but also provides credence to the argument that narrow passages provide the context required to derive a common understanding of the communication method for drivers (Deppermann, 2019). The context provided by narrow passages may also explain why the use of hand gestures from an interaction partner was similarly perceived as a sign that an interaction partner intended to give way (74 %), whilst the results also highlighted that eye contact indicates an intent to give way, with the opposite being true for a lack of eye contact as it suggests that the opposing driver may not have seen them or that they had already decided to proceed first (e.g., *"Being completely ignored,* i.e.*, no eye contact"* – Participant ID (PI) 4315937*)*.

Regarding implicit signals, participants highlighted the importance of the lateral movement of the vehicle. Pulling in (84 %) was the implicit communication most commonly perceived as a giving way action, whilst remaining central on the road (81 %) was similarly highly perceived as being a sign that a driver did not intend to give way, in line with previous findings (Miller, Leitner, Kraus, & Baumann, 2022; Rettenmaier, Albers, et al., 2020). As stated by Miller, Leitner, Kraus & Baumann (2022), the use and the clarity of lateral position alterations to communicate the intent of a driver to give way or pass through a narrow passage is likely linked to the idea that drivers pulling in remove themselves as an obstacle at the narrow passage conflict point and give the opposing vehicle a clearer path to resolve the interference, with the opposite being true for drivers remaining central at the narrow passage. Focusing on the longitudinal movements of vehicles at narrow passages, accelerating (84 %) and maintaining speed (82 %) were perceived as signs that a driver was unwilling to give way, whilst decelerating (48 %) and stopping (81 %) were classified as giving way behaviours, therefore confirming previous findings (Imbsweiler, Linstedt, et al., 2017; Imbsweiler, Palyafári, et al., 2017; Rettenmaier, Requena Witzig, et al., 2020). These results further indicate, in line with expectations derived from the literature (Kauffmann et al., 2018), that the strength/clarity of a signal makes the intention of an interaction partner more obvious. For example, fewer participants reported that decelerating indicated an intent to give way (compared to stopping), whilst a significant proportion of participants interpreted decelerating but not stopping as signifying an intent to not give way. This difference may be attributed to the fact that not fully stopping during a narrow passage interaction means that a driver is still approaching the conflict point of the narrow passage and thus still potentially reducing the space needed to clear the obstacle. Similarly, accelerating into a narrow passage was perceived by a greater number of drivers as a sign that a driver intended to not give way, despite suggestions to the contrary (Miller, Leitner, Kraus, & Baumann, 2022). Again, this difference between the two communications can be explained by the strength/clarity of the signal to not give way, although the ease at which drivers perceive that their interaction partner is accelerating as opposed to maintaining their speed may mean little discernible differences in the behaviours produced by drivers at narrow passages, as found by Miller, Leitner, Kraus, & Baumann (2022).

These results are important as they extend the current literature by highlighting the ways that drivers communicate during narrow passage interactions in the UK and what they might be expecting from their interaction partner, as well as providing clear indications as to how drivers interpret the meanings of these communications. In the context of AV development these results, therefore, provide AV developers with clarification of the meaning of these different behaviours in a UK setting, ensuring that AVs can understand the intent of their interaction partner and can communicate their intent using these communications clearly. Perhaps more interestingly, the replication of the results found in German-based studies in a UK-setting may also mean that research from Germany concerning external Human-Machine Interfaces and narrow passages is applicable to the UK, not least because there is a need to replace the explicit forms of communication found in this study. Regarding the development of driver behaviour models these results also provide indicators of further parameters that should be included in any proposed models (e.g., vehicle speed, lateral position) and collected from any trajectory datasets when calibrating and validating these models, as these communications inform the decisions made by drivers at narrow passages.

6. Limitations and future work

Despite the findings of the study, there are questions regarding whether the study is prone to response biases (e.g., social desirability) due to the self-reporting nature of the study and the topic of investigation of the survey, i.e., whether participants give way. In addition, the failure to mimic the time-pressures, the cognitive load faced by drivers, and even the ability of the participants to perceive the stimuli investigated in the survey may mean that the actions performed in natural conditions differ from those reported by the participants. Whilst these limitations are problematic, it is argued that because the study has sought to compare the potential impact of the different factors to identify factors of interest, rather than look for the absolute effect of these factors, that the impact of these limitations are mitigated. In addition, previous studies have shown a strong alignment between the results of survey and instrumented vehicle studies (Albert et al., 2014; Marshall et al., 2007; Reimer et al., 2006; Taubman-Ben-Ari et al., 2016). This, therefore, may suggest that the issue of this study may not be whether the nature of the findings are true, but rather what the degree of the effects are, a question especially relevant to the attributes of the give way action and how 'strong' this action is. For example, whilst it was found that drivers who align more with the careful driving style are more likely to give way during a narrow passage interaction, are these drivers willing to give way more than other drivers by decelerating by a greater amount and at a greater rate? It is suggested, therefore, that future studies allow for a greater quantitative and naturalistic insights into driver behaviours at narrow passages to confirm the findings of this study but to also investigate the degree of these effects.

Whilst the survey study provided a means to investigate whether individual factors affected driver decision-making at narrow passages, it was limited in its ability to study the interactions between different variables. Since the nature of a system depends on the interactions between its components (Ottino, 2003), the nature and the degree of the effects found may be different in reality. Similarly, whilst the meanings of various signals and the effects of certain factors were investigated given specific scenarios, the meanings and effects may change in different temporal and spatial contexts. Therefore, it is suggested that future studies should allow for the investigation of the interaction of different factors and communications in driver decision-making during narrow passage interactions.

The study was also limited to investigating driver decision-making at narrow passages. Thus, whilst the study was able to find potential differences in driver decision-making at narrow passages from factors found to affect other driving behaviours (including those related to other cooperative road interactions), the ability to generalise the results to other cooperative deadlock interactions, such as three vehicles approaching a T-junction, is limited, despite the similarities of the interactions within this classification. As such, it is suggested that future studies look to investigate the findings made in this study in the contexts of other deadlock interactions, to ensure that any models developed for these other deadlock interactions incorporate the factors necessary to be representative of driver decision-making.

Lastly, it is worth acknowledging that the findings of this study are culturally dependent and limited to the UK. For example, whilst the study has confirmed the meaning of different communication methods found during narrow passage interactions in Germany in a UK setting, the finding that the use of flashed headlights during narrow passages is associated with giving way may not be transferable to other countries (e.g., Italy) in which the use of flashing headlights is an alternative to the car horn (Tennant et al., 2021). Similarly, the cultural dependence of informal and formal driving rules and how these rules affect driver behaviours, may mean that the motivations and expectations of drivers vary in different countries, meaning that findings regarding the factors investigated in this study are not necessarily transferable to other countries.

7. Conclusion

Narrow passage interactions, characterised as a deadlock cooperative road interaction, require interacting drivers to work together to resolve the interference of who should pass through a road narrowing first. In this interaction, neither driver is able to pass the other without a facilitating action from their interaction partner, with often no formal traffic regulation dictating which driver has priority, and thus who should give way at the conflict point. Despite receiving an increased level of interest from those looking to better understand the interaction, in order to propose driver behaviour models and to develop AVs that can safely navigate narrow passages, the interaction has not been as widely investigated as other driving behaviours and interactions. This is due to the limited range of factors that have been investigated in the context of narrow passage interactions and the limited driving cultural contexts encompassed by the literature. As such, an exploratory survey study investigating the potential effects of factors found to affect other driver behaviours was conducted to broaden our understanding of driver decision-making during narrow passage interactions in the UK.

The study demonstrated that a wide range of contextual factors affect driver decision-making and reduce the likelihood of a driver giving way during narrow passage interactions, potentially due to alterations of perceptions of the cost of cooperation, in line with expectations set from the wider cooperative interaction literature (Lütteken et al., 2016; Stoll, Müller, et al., 2019) and indeed theories within the narrow passage interaction literature (Miller et al., 2021). Among these identified factors the effects of the presence of surrounding vehicles and the vehicle type of the interacting vehicle are particularly highlighted as to their effect on the decision-making of a driver at narrow passages, whilst it is also important to consider the driving styles of interacting drivers. In addition, the meaning of different explicit and implicit communications in a UK context were also found. These findings provide important insights into the factors that need to be analysed when seeking to understand the behaviours exhibited by drivers in narrow passage interactions and, therefore, provide an indication of the factors that need to be considered when producing representative driver behaviour models of the interaction and AVs that can interact safely with human counterparts in narrow passage environments.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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