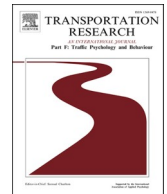




Contents lists available at ScienceDirect

Transportation Research Part F: Psychology and Behaviour

journal homepage: www.elsevier.com/locate/trf

An investigation into driver's perceptions of road flooding and adherence to signage

Matthew Watkins^{a,*}, Maryam Bathaei Javareshk^{a,2}, Thomas Goodge^b,
James Blundell^c, David Crundall^d

^a School of Architecture, Design and the Built Environment, Nottingham Trent University, Nottingham NG1 4FQ, United Kingdom

^b School of Computing Science, University of Glasgow, Glasgow G12 8RZ, United Kingdom

^c Faculty of Engineering and Applied Sciences, Cranfield University, Bedfordshire MK43 0AL, United Kingdom

^d Department of Psychology, Nottingham Trent University, Nottingham NG1 4FQ, United Kingdom

ARTICLE INFO

Keywords:

Floods
Vehicles
Risk behaviour
Dynamic signage
Static signage

ABSTRACT

Driving into flood water is the leading cause of death during a flood in the UK yet represents an unexplored area of research both nationally and internationally. This paper reports on the findings of two quantitative studies. The first a nationwide survey ($N = 185$), which sought to determine driver opinions, attitudes and understanding regarding road flooding, including perception of water depth and water speed. This was followed by experiments to determine the relative saliency of dynamic versus static forms of 20 common UK road signs through eye tracking and memory recall tasks ($N = 44$). This study examines driver's misconceptions of road flooding, lack of adherence to road flooding signage and tests the relative effectiveness of dynamic signage and its relationship to driving experience. The study highlights that traditional flood signage is ineffective – prompting poorer memory recall, whilst dynamic signage demonstrated higher memory recall across all signage tested, with dynamic flooding signage being significantly more effective than the static equivalent for across all demographics.

1. Introduction

Climate change is leading to greater incidents of flooding globally (Gissing et al., 2023; Hiramoto et al., 2025), causing changes in storm patterns (Suarez et al., 2005) and rainfall intensity (Evans et al., 2024) throughout the UK, affecting river levels and flows (Hannaford & Marsh, 2008; Prosdocimi et al., 2014; Robins & Lewis, 2019). Whilst there has been a significant focus on the effects of flooding to housing stock (Sayers et al., 2018), the effect on transportation infrastructure and systems is given far less focus and requires addressing (Suarez et al., 2005).

Driving through flood water is the leading cause of death during a flood in the UK (Environment Agency, 2019) and high income countries worldwide particularly Australia and the US (Evans et al., 2024; Gissing et al., 2023; Panakkal & Padgett, 2024). Just 30 cm of water can float a small car with only 50 cm required to float a large 4×4 (Kramer et al., 2016; Martínez-Gomariz et al., 2017; Pregnotato et al., 2017). Once a vehicle begins to float, there is the possibility that it will be carried downstream (Evans et al., 2024;

* Corresponding author.

E-mail address: m.watkins@lboro.ac.uk (M. Watkins).

¹ Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University

² Faculty of Engineering and Applied Sciences, Cranfield University

<https://doi.org/10.1016/j.trf.2026.103639>

Received 22 May 2025; Received in revised form 20 March 2026; Accepted 22 April 2026

Available online 5 May 2026

1369-8478/© 2026 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

Gissing et al., 2023; Kellar & Schmidlin, 2012), especially where water is flowing (Evans et al., 2024) which can result in entrapment and drowning of occupants (Drobot et al., 2007; Evans et al., 2024; Shah et al., 2018; Versini et al., 2010). Despite this, the dangers of driving through flood water are not widely recognised amongst the public. Key reasons cited for drivers entering flood water are a lack of awareness of the dangers (Franklin et al., 2014) or that existing warnings are not taken seriously (Drobot et al., 2007; Shah et al., 2018). In the UK both possibilities are likely, due to the absence of flood-related information in the UK Highway Code (HR Wallingford, Flood Hazard Research Centre and Analysts, R., and P, 2006; The Department for Transport, 2020), and a lack of focus in government led UK road safety campaigns (HR Wallingford, Flood Hazard Research Centre and Analysts, R., and P, 2006), which typically feature more prominent issues such as drink driving, the wearing of seatbelts and awareness of motorcycles. This is in contrast with other countries such as the USA and Australia, who specifically target road flooding through learner handbooks (Hamilton et al., 2023) and driver awareness campaigns (Drobot et al., 2007; Gissing et al., 2016). With the absence of driver instruction and awareness campaigns, the sole strategy implemented in the UK to minimise road flood incidents is through the use of road signage for which there has been very little research into the effectiveness especially within a UK context.

Existing literature concerning road flooding signage (Ahmed et al., 2020; Higgins et al., 2012) and drivers' responses to road flooding is predominantly from an Australian (Gissing et al., 2016; Haynes et al., 2017), or North American (Drobot et al., 2007; Higgins et al., 2012) perspective, with a literature review noting a distinct lack of any European studies (Ahmed et al., 2018). While there is an distinct absence of UK-specific literature on the effectiveness of flooding signage, Australian (Ahmed et al., 2020; Gissing et al., 2016) and Malaysian (Shah et al., 2018) researchers have reported existing road signage to be ineffective. This paper seeks to address this literature gap by exploring drivers' reactions to flooding situations and the current forms of flooding signage in the UK to understand their adherence (or lack of) to road signage. The study also considers the potential for dynamic forms of signage to increase adherence, by comparing the effectiveness of a range of dynamic and static road signs. The research is presented through two studies as part of a wider project involving field trials of a prototype dynamic sign and flooding detection system at a well-known national road flooding hotspot (Smith, 2018).

1.1. Key hypotheses

These two studies sought to test three key hypotheses:

First, we hypothesised that demographic factors play a key role in the decisions around whether to enter flood water, with male drivers often found more likely to be involved than females to enter flood water (Ahmed et al., 2020; Diakakis & Deligiannakis, 2013; Hamilton et al., 2018; Haynes et al., 2017; Smith, 2018). Other demographic factors include location familiarity, with drivers residing in rural areas (Diakakis & Deligiannakis, 2013; Gissing et al., 2019) being more willing to enter flooded locations, and the type, size and ownership mode of vehicle driven. Drivers of 4 × 4's are reportedly more likely to enter flood water (Ahmed et al., 2020; Coles, 2008; Gissing et al., 2016; Hamilton et al., 2018; Haynes et al., 2017).

Secondly, we questioned whether drivers are less likely to react to flooding 'warning' signage than other mandatory forms of signage such as speed limits. In the UK, warning signage is typically triangular, whilst signage that gives orders and is considered mandatory consists is circular, with rectangular forms for information and directional signage (The Department for Transport, 2020).

However, there is a wide spectrum of warning signage, giving advance warning of a variety of road features, such as junctions, and potential hazards such as flooding, wildlife, or potential rock falls. Whilst flooding signage is given as a warning rather than an order, the consequences of not heeding the warning could have similar risk outcomes to disregarding mandatory speed and stop signs for example.

Our third hypothesis predicts that dynamic forms of signage utilising LEDs should be more effective at evoking adherence than traditional static screen-printed aluminium signage. It is proposed that dynamic signage could be considered more visually salient

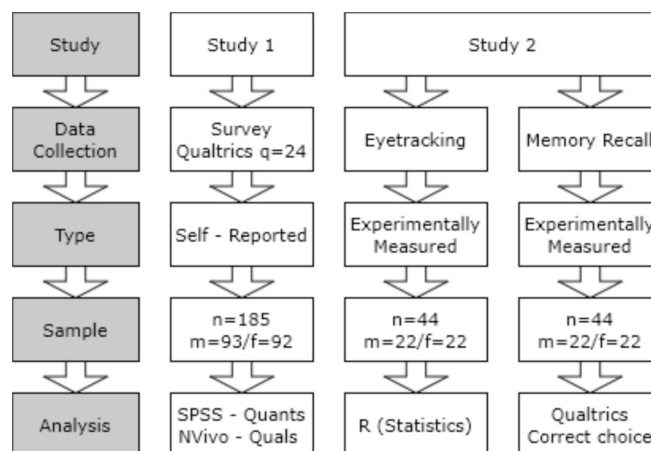


Fig. 1. Methodology Diagram

(Luck et al., 2021; Theeuwes, 2010) than static forms due to the greater brightness and the vehicle activated eye-catching nature of dynamic signage. Adopting a more prominent bottom-up visual selection approach (Theeuwes, 2010) in contrast to the traditional static forms, especially for signage such as flood signage that may not be expected or anticipated. It is proposed that this would cause drivers to react more rapidly and respond more consistently. Furthermore, drivers may perceive a dynamic sign to be more temporally relevant than a static sign, especially in respect to flood signage which may remain visible after the flood waters ahead have receded, therefore a dynamic sign could therefore be perceived as more trustworthy by drivers.

2. Methodology

A range of quantitative methods were employed as highlighted in [fig. 1](#). The first study consists of an online survey that sought to measure existing understanding, attitudes, adherence toward road flooding and signage, and drivers' willingness to drive through flood water. This was complemented by a second study that utilised eye tracking experiments and memory recall tests to determine the effectiveness of signage, comparing static signage to comparable dynamic versions.

2.1. Experiment 1 Online Questionnaire

An electronic questionnaire was developed via Qualtrics, an online platform and was advertised through a variety of social media channels. The objective of the questionnaire was to examine the perception and attitudes of drivers regarding static and dynamic traffic signage and road flooding scenarios. The survey was structured in four parts: demographic questions, perceptions of static and dynamic flood signage, perceptions of flooded roads, and attitudes to different flooded road scenarios displayed in photographs and video clips. Quantitative data was analysed using SPSS, while qualitative data was analysed in NVivo following a content analysis approach. This involved systematically examining participants' open-ended responses to identify recurring themes and patterns, enabling qualitative insights to be transformed into quantifiable data. This research was approved by the Ethics Committee at Nottingham Trent University (ID 1627983). The research was conducted in accordance with the Declaration of Helsinki and adhered to the ethical guidelines of Nottingham Trent University for research integrity and health and safety. All participants were informed about the aim and procedure of the study and were asked to provide consent before taking part in the study. No deception was involved, and participants were debriefed after their participation.

2.2. Participants

In total, 414 respondents undertook the questionnaire, which was reduced to 185 responses (93 males, 92 females) after removing incomplete and non-UK responses. Respondents had an average age of 40.6 years ($SD = 15.9$), ranging from 19 to 81 years old, Appendix 1 shows our data representativeness compared to DVLA license holder data for the same period. These respondents had an average of 13.9 ($SD 4.74$) years' driving experience since passing their test and drove between 5001 and 10,000 miles per year, or 101–200 miles per week reporting a greater proportion average of 52% of leisure miles travelled. The majority (83.7%) stated that they fully owned their car, whilst 10.8% reported driving a leased/ PCP car, followed by 2.1%, 1.8% and 1.6% who reported using company cars, hire cars, or cars belonging to a family member. Participants were asked the type of vehicle they most frequently drive; the highest percentage (25.95%) reported a supermini such as a Ford Fiesta or similar while the least represented vehicle was a luxury saloon such as a Mercedes S class or similar (0.54%). SUV/4 × 4 drivers made up 14% of the sample.

Using a 5-point Likert rating scale, participants were asked how frequently they drive in the following areas ([Table 1](#)).

2.3. Key questions

The questionnaire contained 24 questions. The first eight questions related to demographic information detailed in the participant's section. The first section contained five signage questions which required drivers to choose a single statement that most closely aligned with their response to the signs depicted. as shown in [fig. 2](#).

The second and third sections of the questionnaire included a range of questions pertaining to the respondent's response to road flooding with three questions concerning behaviour and eight concerning their judgment of road conditions. In total five questions were open response, and three questions were closed response, two of which were yes or no and one required respondents to select the maximum safe water heights from a range given. The final three questions were posed as Likert questions.

Drivers were shown both images in [fig. 3](#) of approaches to flooded roads described as a 30mph (left) and on a 50mph (right) asked to consider themselves in the car most frequently used and to indicate their approach speed arriving at the water and their speed when

Table 1
Key demographic characteristics of type of areas driven by drivers.

Driven Areas	Never	Seldom	Sometimes	Frequently	Always
1. Urban areas (town, city routes)	0.00%	7.03%	30.81%	53.51%	8.65%
2. Suburban areas (residential)	0.00%	8.65%	21.08%	61.62%	8.65%
3. Rural areas (countryside)	1.62%	17.30%	34.05%	40.00%	7.03%
4. Motorways	3.24%	16.76%	37.84%	34.05%	8.11%



Fig. 2. Three types of flood signs and mandatory signs presented to participants (Burge, 2017; Scrimsign, 2020).

driving through the water.

Respondents were shown [fig. 4](#) and asked to determine the depth that they deem it safe to drive through flood water.

To test their judgment of water speed respondents were shown a video of the ford in [fig. 5](#) three times, changing the speed of water from slow to medium and fast. They were then asked to judge the situation in each video based upon the water flow, giving a yes or no decision on whether they would proceed through the ford and asked to clarify their reasons for their decision based on an open-ended question box.

To assess each driver's attitudes and judgment toward a flooded road, in the three final questions respondents were shown three photographs depicting three road flooding scenarios. Scenario A sought to assess the driver's judgment based on effect of the vehicle ahead, which had passed through the water, scenario B sought to assess the driver's judgment of shallow water with no other cars but fencing and gates for reference, and scenario C sought to assess the driver's judgment of deep-water in which a van and a small car had become stuck. The respondents were asked to respond to the predetermined questions ([Table 3](#)) using a 5- point Likert scale stating for each of three scenarios.

2.4. Experiment 2 method - eye tracking and memory response

The first study examines demographic factors such as age and driving experience and their relationship with willingness to go through the flood and dynamic flood signage. However, due to the survey nature this is limited to observation of static images. Therefore, the second study showed participants driving perspective videos encompassing signage to test their responses in a more realistic setting using video and eye tracking followed up by a memory recall activity. Additionally, we created a fully operational prototype of dynamic flood signage ([fig. 6](#)), which was deployed with a water level and flow rate sensing bollard along a flood-prone road to assess its efficacy in capturing the attention of drivers. We incorporated this signage into our video footage alongside a breadth of conventional road signs in both their static and dynamic forms to explore the survey findings and evaluated the drivers' responses. The second experiment also sought to assess the attentional differences of drivers in response to static and dynamic traffic signs to test the hypothesis that drivers would react and respond to dynamic signage more rapidly and consistently than static forms.

2.4.1. Design

An experiment was conducted to measure the effect of driving experience (Experienced versus Novice) on gaze behaviour and recall ability between the type of road sign (Static versus Dynamic). A mixed design was used with driving experience as a between groups factor and type of road sign as a within groups factor. This research was approved by the Ethics Committee at Nottingham Trent University (ID 1627983). The research was conducted in accordance with the Declaration of Helsinki and adhered to the ethical guidelines of Nottingham Trent University for research integrity and health and safety. All participants were informed about the aim and procedure of the study and were asked to provide consent before taking part in the study. No deception was involved, and participants were debriefed after their participation.

2.4.2. Participants

A sample of forty-four drivers comprising of an equal split of male and female participants were assigned into one of two groups. This sample size is beyond the 40 threshold recommended in the literature for studies concerning AOI's (Hoogerbrugge et al., 2025). The first group consisted of twenty novice drivers, with 3 years or less of driving experience (mean age: 23 years, mean experience: 1.5 years), whilst the other twenty-four participants were classed as experienced drivers with more than 3 years of driving experience, (mean age: 36.7 years old, mean experience: 11 years). All participants were recruited through internal advertisement at Nottingham Trent University.



Fig. 3. Approaches to Fords on two different speed roads.



Fig. 4. Judgment of water depth.

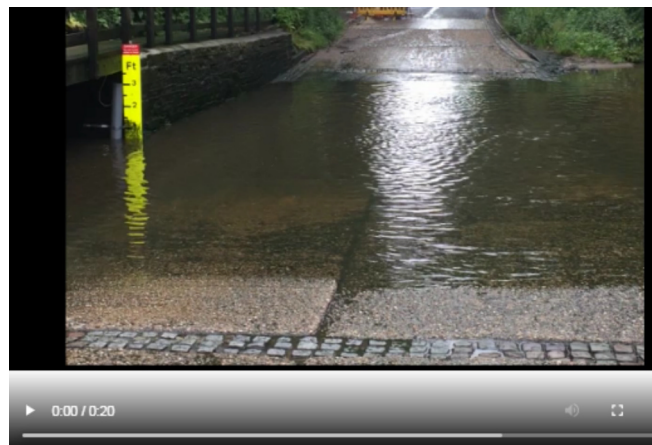


Fig. 5. Video screen shot of the flooded road.

2.4.3. Apparatus and stimuli

Participants were told that they would be watching video clips depicting real on-road footage and would be asked to answer some questions at the end, with no false task given. The stimuli consisted of 20 recorded videos clips, depicting matched pairs of 10 common road signs (fig. 6) edited from hours of footage captured through routine driving. This footage was filmed using a windscreen mounted Go-Pro camera to depict the point of view of the driver and edited using Adobe Premier Pro software. Each video clip was cropped to last approximately 50 s, with the 20 clips being split into 10 pairs containing a matched static and dynamic variant of each sign for comparison. Each participant was shown all 20 video clips in a randomised sequence. Care was taken to ensure that each sign pair was viewable for the same duration.

The stimuli were presented on a computer screen measuring 48.3×30.5 cm connected to a SensoMotoric Instruments' Remote Eye-tracking Device, sampling at 500 Hz (SMI RED 500). Eye tracking data was collected to provide an insight into participants' attention to signage during the presentation of the videos. However, to assess whether participants sufficiently processed the signs shown, they were presented a questionnaire immediately after the video presentation on a Lenovo ThinkPad X 260 laptop that assessed their level of memory recall of the target signs. The memory test conducted in Qualtrics contained 20 arrays, each containing 4 sign images of which one had appeared in the preceding eye tracking phase of the study, while the other 3 signs were distracters. The position of the correct sign within the array was randomised across trials. The use of this combined eye tracking and recall approach address criticisms in the literature of a sole recall approach, negating potential subconscious reactions to signs (Crundall & Underwood, 2001; Jamson & Mrozek, 2017).

Type of sign	Static	Dynamic
Flood <i>Right Prototype</i> <i>Dynamic flood sign</i> <i>created for study</i>		
Bridge		
School crossing		
Crossroad ahead		
Junction on right bend		

Fig. 6. Matched pairs of 10 common road signs.

2.4.4. Procedure

Participants were tested within an eye tracking laboratory at Nottingham Trent University. Each was given an overview of the study, completed the consent form and before testing, was briefed individually by the experimenter with the details of the experiment explained to them. Instruction slides were also displayed on their computer screens. Each participant was seated approximately 60 cm from the screen and told that they would see some video clips taken from the perspective of a driver. The total horizontal viewing angle for the screen was 44.4 degrees, and the total vertical viewing angle was 25.0 degrees, based on a viewing distance of 60 cm. The Areas

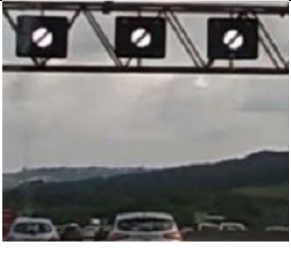
Motorway Information sign		
National speed limit		
Maximum speed limit of 50 miles per hour		
Maximum speed limit of 40 miles per hour		
Maximum speed limit of 30 miles per hour		

Fig. 6. (continued).

of Interest (AOIs) focused on the road signs, these were approximately 200–300 pixels wide and 150–200 pixels tall, depending on the size and distance of the signs in the video footage. Meanwhile, eye movements were measured and considered valid if they fell within a specific temporal window, defined by the AOI onset and offset points for each clip. After viewing all video clips, participants were presented with the recall memory test questionnaire, for each question participants were asked to select the sign that they had seen earlier in the eye tracking experiment. These questions aimed to assess the level of memory recall and were presented randomly to participants. All drivers were given a £10 Amazon voucher for their participation in the study.

3. Results

3.1. Study 1 results

The primary objective in the first section of this study is to examine the direction and strength of associations between key variables rather than to establish causal relationships. Correlation analysis is therefore employed as an appropriate exploratory technique to identify potential relationships that may warrant further investigation. Pearson correlations were undertaken to investigate the relationships between the demographic variables and drivers' willingness to drive through a flooded road or a ford. The average score for willingness to drive through flood waters was (M : 93.64) across the whole sample, ranging from 48 to 119, out of a potential score of 120 derived from the questions posed for the three scenarios described in section 2.1.2. The correlations shown in full in Appendix 2 show a positive relationship between variables of age ($r = 0.342$, $N = 183$, $p < .001$), driving license period ($r = 0.276$, $N = 185$, $p < .001$) and likelihood of driving through floodwaters. As the age and driving license period increases, the probability of driving through water increases too, suggesting that experienced and older drivers are more willing to go through water compared to novice drivers. No meaningful relationships were found between demographic variables of sex, miles driven, leisure mileage, ownership of the car, type of the car, prior experience of driving through flood water or driven locations (urban, rural, suburban, motorways) with willingness to drive through flood waters (all $P > .05$).

For the STOP sign, drivers were asked to select one response from three potential actions. Of the total sample, 87.57% of drivers reported adherence and selected "I would come to a complete stop", whilst 10.27% selected "I would slow down but proceed if they thought it safe to do so" (i.e., treating the sign more as a 'Give Way' sign). The remaining 2.16% of respondents selected "I would turn around to find another way if it is easy to do so", which suggests that these participants misunderstood either the sign or the question.

For the 30-mph sign, drivers were given four responses to choose from. Of the total sample, 48.65% of the sample reported that they "would not drive above this speed", 35.14% stated they "would drive at this speed" (i.e., viewing the speed sign as a target speed rather than a maximum limit). Of the remaining sample, 12.43% stated they would "reduce my speed to this level if a speed camera is present" while 3.78% stated that they would "treat the sign as an advisory speed limit". These results for the speed sign suggest a slightly lower compliance than the STOP sign but are close in respect of overall compliance. Whilst these figures for the mandatory static signs don't suggest 100% adherence particularly in relation to the speed sign, it does suggest a relatively high level of compliance amongst the sample, with only 12.4–16.2% demonstrating violating behaviour.

A comparison of responses to the three flood signs, suggested that the dynamic ($M = 3.20$, $SD = 0.78$) and hybrid flood signs ($M = 3.29$, $SD = 0.67$) in comparison to the static flood sign ($M = 2.87$, $SD = 0.69$) elicited a far higher incidence of drivers electing to turn around and a lower incidence of decisions based on the actions of other drivers. A one-way within subjects ANOVA was conducted to compare the effect of sign type on driver adherence in static, dynamic and hybrid sign scenarios. The result showed that mean sign scores differed significantly across these three scenarios, $F(2, 368) = 30.354$, $p < .001$, $\eta_p^2 = 0.142$. Furthermore, a post hoc pairwise comparison using the Bonferroni correction indicated a significant difference between the dynamic and hybrid signs versus the static sign ($p < .001$), but no significant differences were found between the dynamic and the hybrid sign ($p > .001$). Whilst both the static and dynamic signs represent identical information in a warning-sign format, the dynamic sign is reportedly treated with more adherence than the static sign. The hybrid sign also ostensibly receives more credibility from respondents, despite it being informational in shape.

These results shown in [fig. 7](#) align with the inferential analysis in [table 2](#), which examined the relationships between the three types of flood signage and the willingness to drive through flood water. There is a statistically significant positive relationship between the static flood signage and willingness to drive through flood water ($r = 0.316$, $p < .001$), suggesting that where signage is present static flood signage is the least effective at reducing the willingness to drive through floodwater.

Though our general measure of willingness to drive through flood waters correlated with willingness to ignore a static flood sign, this was not the case with the dynamic and hybrid signs. This suggests that only the dynamic and hybrid signs moderate pre-existing tendencies to drive through water.

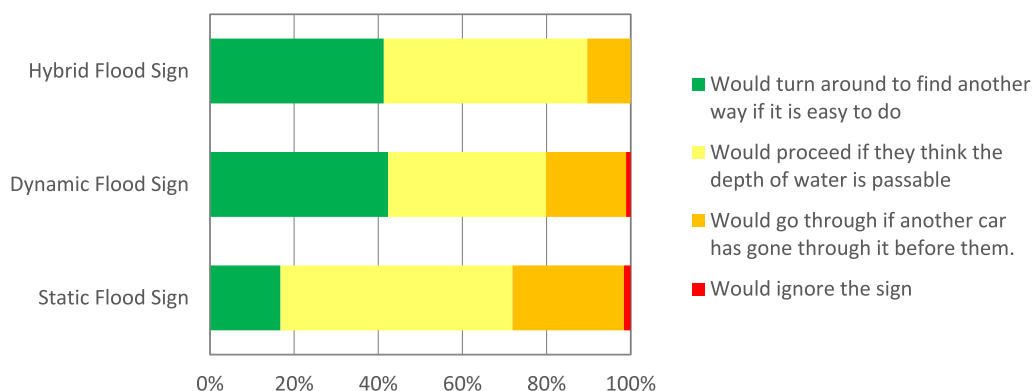


Fig. 7. Percentage of respondent's responses to the different options when presented with three flood signs.

Table 2
Correlations between types of flood sign and willingness to drive through flood waters.

	Static flood sign	Dynamic flood sign	Hybrid flood sign
Willingness to drive through flood waters	0.316 $p < .001$ $N = 185$	0.181 $p = .01$ $N = 185$	0.114 $p = .12$ $N = 185$
Static flood sign		0.496 $p < .001$ $N = 185$	0.235 $p = .001$ $N = 185$
Dynamic flood sign			0.470 $p < .001$ $N = 185$

Respondents were asked questions relating to their knowledge, experience and intended behaviour on flooded roads. When asked if they had driven through a flooded road or ford in the past, 71.35% of drivers stated that they had, whilst 28.65% had not.

Participants were asked when approaching a flooded road or ford on a 30mph versus a 50mph road *what speed they would aim for 10 m before the water* and *what speed they would aim for when in the water* by entering a numerical value in an open box for which no suggestions were given, the results of which are shown below in [fig. 8](#).

The hypothesis was that drivers would adjust their speed by a similar relative amount on both roads rather than to an absolute figure suggesting that on a 50mph road they would drive more rapidly through water than on a 30mph road. However, [fig. 8](#) suggests this not to be the case. A 2×2 within subject Analysis of Variance (ANOVA) was conducted on participants' speed responses across the variables of speed limit (30 mph vs. 50mph) and point in the drive (on approach vs. driving through the flood water) on participants speed ratings. This identified a significant main effect of timing ($F(1,180) = 199.906$, $MSe = 19.559$, $p < .001$) with participants rating their speed as significantly higher before the flood ($M = 13.03$ mph) than during the flood ($M = 8.38$ mph). Furthermore, a significant interaction was found between road speed and timing ($F(1,180) = 199.906$, $MSe = 0.000$, $p < .001$). However, no significant difference ($P > .05$) is seen between scenarios of 30mph road (Mean before water = 13.03, Mean during water = 8.38) versus 50mph roads (Mean before water = 12.85, Mean during water = 8.20).

Respondents were asked to indicate at what depth they would deem it safe to drive through flood water. They were given nine options initially increasing in 0.25 m increments and from 1.5 m in 0.5 m increments and a with the graphic shown in [fig. 4](#). The majority, 81.6% correctly indicated the lowest level, less than 0.25 m which is below the 0.3 m depth at which a small car could float, 16.8% chose 'less than 0.5 metres', while two respondents chose 'less than 0.75m' with one participant choosing 'less than 3m' ([Fig. 9](#)).

When asked about their awareness of how flowing water speed can affect driving, 73.5% of participants stated they were aware, and 26.5% not aware of the impact. Their open responses however, suggested otherwise with only 23.2% of participants stating the speed of water as a factor in whether to proceed into the ford although most of these participants had considered the water flow as slow

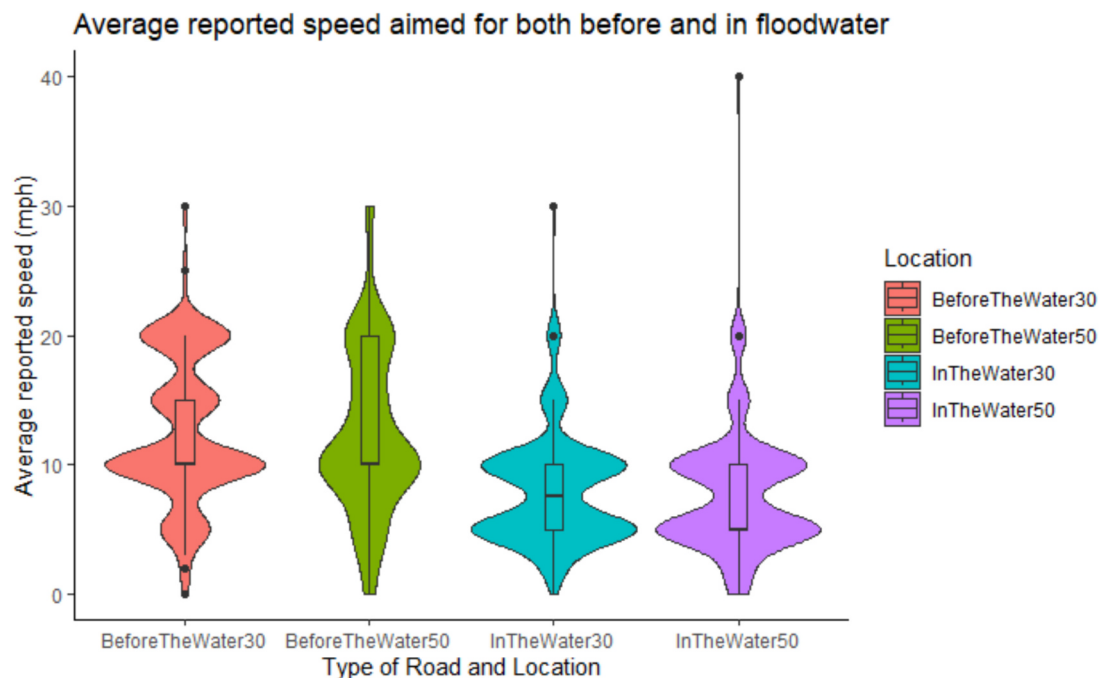


Fig. 8. Participants' responses for their approach and in water speed scenarios for 30mph and 50mph roads.

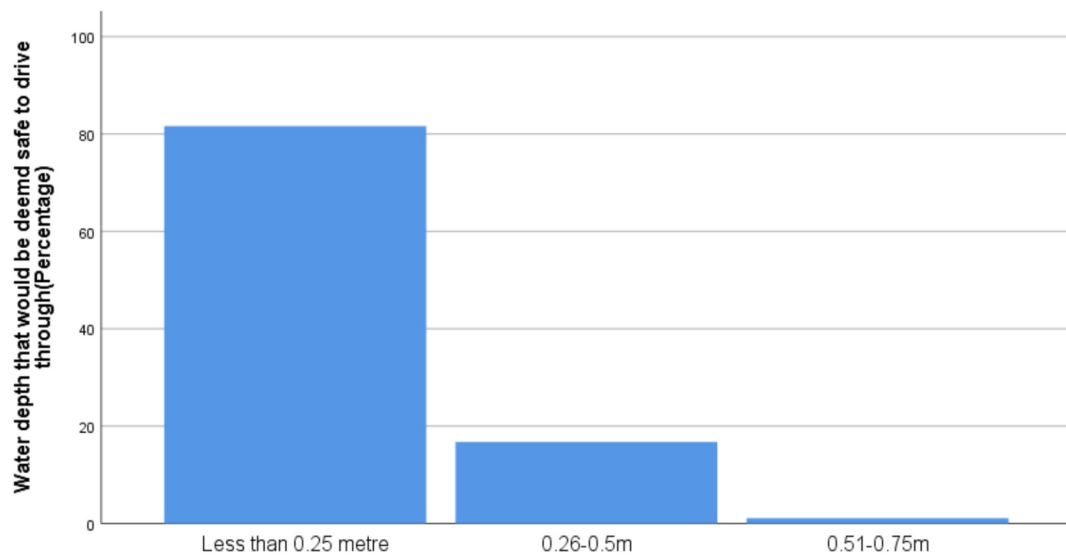


Fig. 9. Depth at which it is deemed safe to drive through flood water (anomaly responses >1 m removed).

in all three videos. A further 46% judged the “depth of water” as a proxy for flow, whilst other responses considered their perception of their car’s suitability, potential damage to their car, whether there were vehicles ahead (although none were shown in the videos), visibility and statements concerning whether they class the ford as safe or dangerous. This suggests drivers lack an understanding of the importance of water current (FitzGerald et al., 2010) and fail to consider this when deciding whether to enter a flooded road, even though it is a key factor in risk of entrapment and drowning (Evans et al., 2024). This gap between stated awareness and actual consideration of flow speed suggests that participants may overestimate their understanding. It highlights that awareness does not always translate into accurate risk judgment, emphasizing the need for clearer education on how water velocity affects driving safety.

Driver’s attitudes and judgment toward a flooded road, from their responses to Scenario A (following car), Scenario B (shallow water no marker) and Scenario C (deep water with stranded car):

A 1×3 repeated-measures Analysis of Variance (ANOVA) was conducted to evaluate the null hypothesis that there is no change in participants’ overall responses to flood in these three scenarios (i.e., participants do not identify that the danger from entering the water increases across the three pictures). However, the results of the ANOVA indicated significant difference across the three scenarios in participants’ ratings of how much they agreed with a series of behavioural statements (e.g., “I would proceed if another car has

Table 3

Main effects means in a 1×3 ANOVA.

Statement	Main effect		Means			
	F	p*	A	B	C	
I would come to a complete stop and turn around to find another way	634.225	<0.001 (sig)	2.12	> 4.65 **	= 4.76	
I would proceed if another car has gone through it before me	335.118	<0.001 (sig)	1.94	> 3.48 **	> 4.4 **	
I would make a judgment to go through it or not based on my previous experience of this or a similar road	137.388	<0.001 (sig)	1.63	> 2.71 **	> 3.49 **	
I would proceed if I feel under pressure from passengers	59.324	<0.001 (sig)	3.7	> 4.68 **	> 4.8 **	
I would proceed if I feel under pressure from drivers behind me	111.697	<0.001 (sig)	3.7	> 4.68 **	> 4.8 *	
I would proceed if I’m in a rush or being quite late for (a meeting/work/wedding/pre-booked event)	161.107	<0.001 (sig)	3.34	> 4.45 **	> 4.73 **	
I would proceed if there is an emergency	208.543	<0.001 (sig)	2.35	> 3.73	> 4.31	

* $p < .05$
** $p < .01$

gone through it before me"). As shown in table 3, the significant main effects and associated contrasts indicate that in all statements (except the first), drivers would be less cautious going through the water in scenario A in comparison to scenario B, and less cautious in scenario B in comparison to scenario C. Regarding the first statement however the contrast effect between scenario B and C is not significant.

Fig. 10 presents the percentage of participants who specified each response.

The closeness of the results between the deep and shallow scenarios is quite surprising suggesting that without seeing the car as a reference the respondents were more cautious in both the shallower and deeper water scenarios. Whilst the shallower image showed a long expanse of water, it could be seen from roadside features such as signposts and fencing to be relatively shallow. Whilst this agrees in part with the findings by Higgins et al. (2012) in relation to the breadth of the water surface potentially putting drivers off, it negates the findings of other studies which found that drivers judged the depth of the water via the roadway and surrounding topological visual cues (Coles, 2008; Higgins et al., 2012). However the findings above do agree with findings from both the U.S. and Australia that the presence of other cars crossing the water gives drivers confidence to drive through the water also (Coles, 2008; Gissing et al., 2016).

3.2. Study 2 results

The eye tracking data was initially processed and classified using SMI BeGaze (Version 3.6.52), and then analysed in RStudio (2024.09 Build 394) using the lme4 (Bates et al., 2015), lmeTest (Kuznetsova et al., 2017) and report (Makowski et al., 2023) packages. Plots were created using the ggplot2 (Wickham, 2016) package. A series of descriptive and inferential analyses were conducted for Sign Type (static and dynamic) as a within groups measure and Driver Group (novices and experienced) as between groups factors for four dependent variables: fixation count, fixation dwell time, time to first fixation and memory recall. We consider fixation count as the proportion of times that participants attended to the parts of the scene defined as an AOI (i.e., the sign). The fixation duration time concerns the amount of time in which drivers held their focus on a particular AOI for an extended period of time, calculated using SMI BeGaze's event detection algorithm for fixation classification. Time to First Fixation referred to the difference between the onset of an AOI (e.g., the appearance of a sign) and the moment when the participant first fixates on that AOI, indicating how quickly attention was directed to that specific region of interest. Finally, the memory recall test measured the number of correct signs participants were able to recall. By combining these eye tracking measures with the recall scores, we were able to assess whether drivers could process the different sign types and how long each sign drew their attention for.

3.2.1. Number of fixations on sign AOI

A Chi square test of independence found there was a significant difference between the number of times participants fixated on Dynamic and Static signs ($\chi^2 = 42.46$, $df = 9$, $p < .001$), with a higher number of fixations on Static signs.

Chi square Goodness of fit tests were conducted for each of the individual Sign types, revealing that there were significant differences for the Speed limit 50 ($\chi^2 = 15.87$, $df = 1$, $p < .001$), Flooding ($\chi^2 = 4.91$, $df = 1$, $p = .03$) and National Speed ($\chi^2 = 17.31$, $df = 1$, $p < .001$) signs. (See Fig. 11).

A follow up Chi square test of independence found there was a significant difference between the number of times participants fixated on Dynamic and Static signs for each Driver Group ($\chi^2 = 45.84$, $df = 27$, $p = .013$). However, post hoc comparisons found no significant differences between the number of fixations for each Driver Experience Group on each Sign type (see Fig. 12).

3.2.2. Fixation duration

Fig. 13 shows the average fixation duration for each Driver Group on the different Sign Types, calculated from 745 total fixations during the period when the sign AOI was active during each trial. Due to the non-normal distribution of the data, fixation duration was z-scored and scores above 3 standard deviations away from the mean were removed as outliers, leaving 651 fixations for analysis.

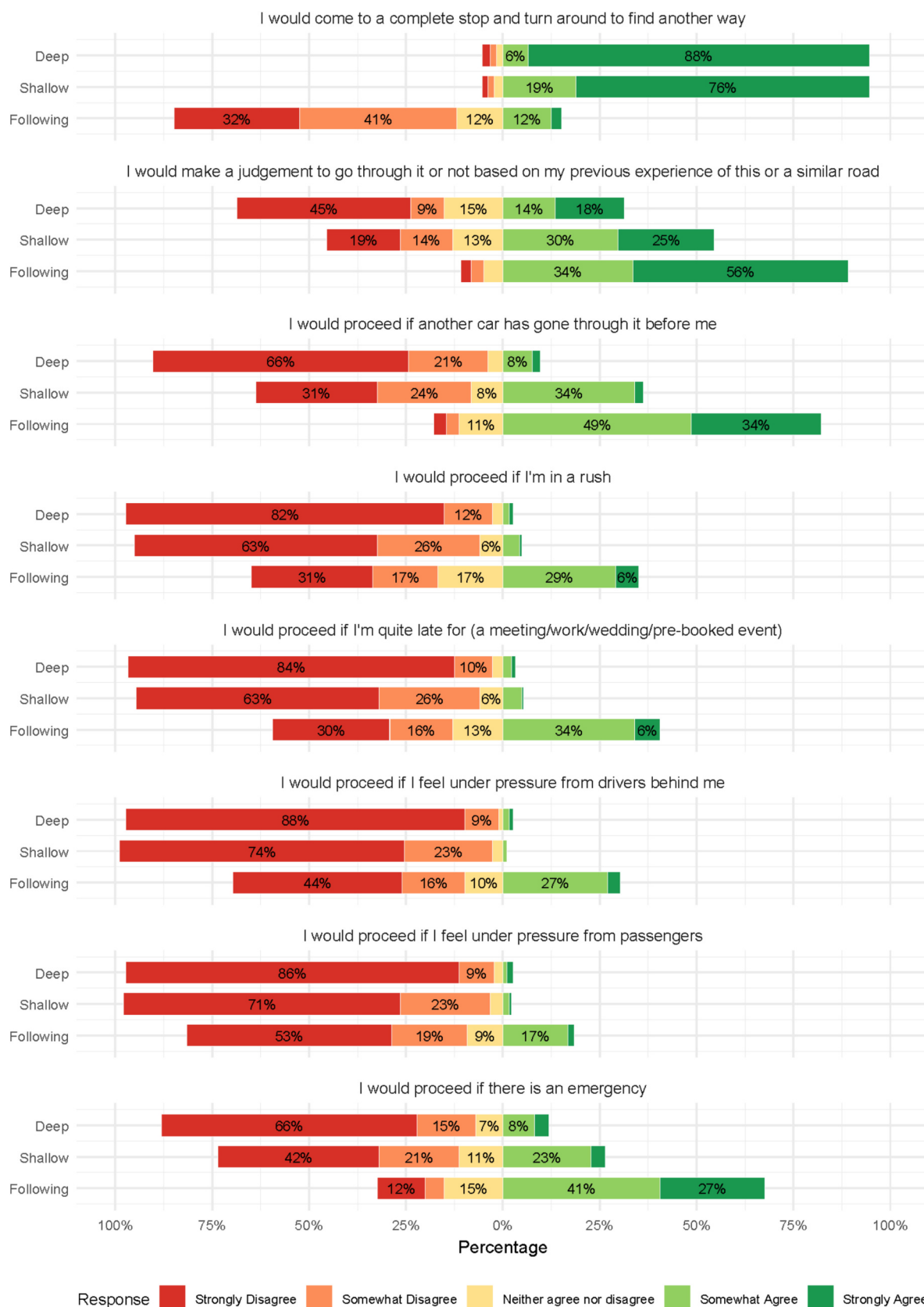
A 2×2 mixed design ANOVA with Driver Group as a between subjects' factor and Sign Type as a within subjects' factor found no significant differences between average fixation duration for the effect of Sign Type ($p = .9$), Driver Group ($p = .71$), nor any interaction ($p = .4$).

To analyse whether the length of time the sign was visible had any effect on dwell time of participants, a linear mixed effects model with Driver Group and Sign Type and AOI Length as main effects was fitted, and Participants and Trial Number as random effects. This model was compared to a null model where all variables were fitted as random effects and was found to explain a significantly greater proportion of the variance (Null Model AIC = 8955.2.1, BIC = 8991.0; Mixed Effects Model AIC = 8951.5, BIC = 9000.8; $p = .02$). However, there were still no significant differences (see fig. 13) between average fixation durations for Driver Type ($p = .92$) or Sign Type ($p = .42$), nor any interaction effects (Sign Type $\times$ Driver Group: $p = .387$, Driver Group $\times$ AOI Length, $p = .74$, Sign Type $\times$ AOI Length: $p = .266$, Full Interaction: $p = .3$).

3.2.3. Time to first fixation

Fig. 14 shows the average time until the first fixation on a sign for each Driver Group and Sign Type. The time between the start of the AOI onset and the first fixation was calculated for each participant. A 2×2 mixed design ANOVA with Driver Group as a between subjects' factor and Sign Type as a within subjects' factor found a significant difference between the first fixation time for Sign Type ($F(1) = 48.344$, $p < .001$, $\eta^2 = 0.15$). Post-hoc tests revealed significance for both Experienced ($p < .001$) and Novice ($p < .001$) drivers between Static and Dynamic Signs. However, there were no significant differences between Driver group ($p = .084$), nor any interaction ($p = .02$).

Once again, to account for the effect of the length of the AOI window, a linear mixed effects model was fitted with Sign Type, Driver



(caption on next page)

Fig. 10. Participants' responses by statement where green colour represents the least risky behaviour and red colour represents the riskiest behaviour. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

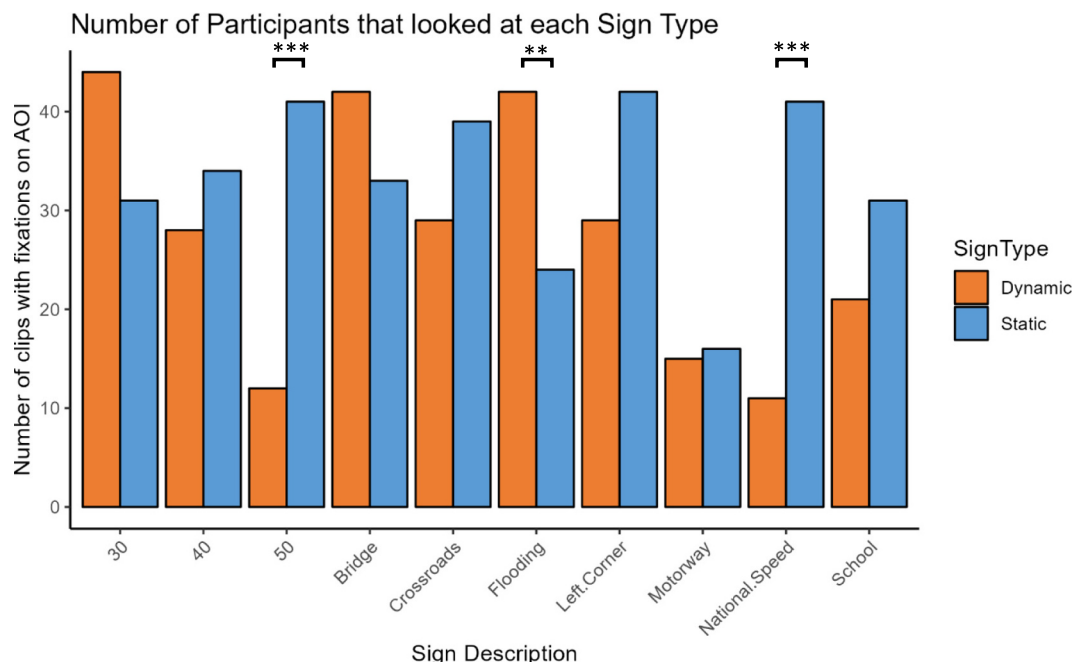


Fig. 11. A column plot showing the number of participants with at least one fixation within the AOI for each sign type. There were significantly higher number of participants that fixated on the Static 50 mph and National Speed limit signs. However, a significantly higher number of participants fixated on the Dynamic Flooding sign.

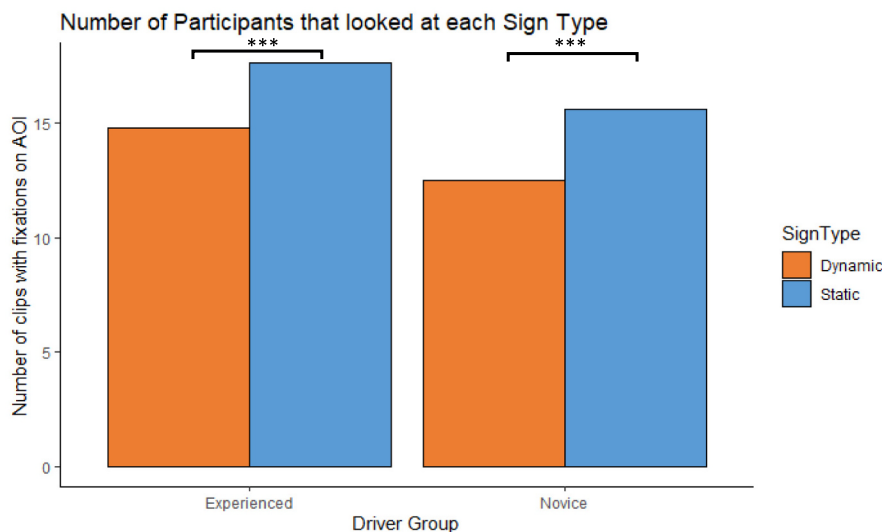


Fig. 12. A column plot showing the number of participants with at least one fixation within the AOI for each sign type.

Group as fixed effects, and Participant, Trial Number and AOI Length as random effects, which had substantial explanatory power (*conditional* $R^2 = 0.48$). This model was compared to a null model and found to explain a significantly greater proportion of variance (Null Model AIC = 4978.3, BIC = 5003.4; Mixed Effects Model AIC = 4972.0, BIC = 5000.7; $p = .004$). The model was also compared to a model without AOI Length fitted as a main effect and was also found to explain a significantly greater proportion of variance (Simpler Model AIC = 5015.9, BIC = 5041.0; Mixed Effects Model AIC = 4972.0, BIC = 5000.7; $p < .001$). Within this model, there was also a significant effect of Sign Type (*Est.* = -2250.91, 95%CI [-4121.31, -380.51], $t(257) = -2.37$, $p = .019$), with significantly shorter

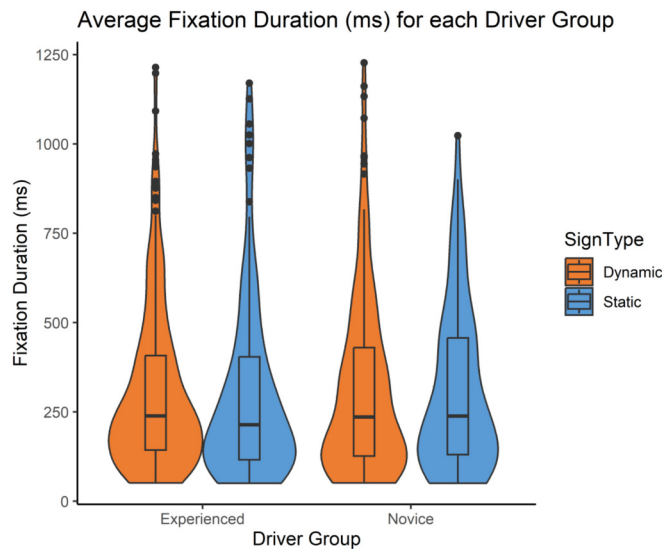


Fig. 13. Violin Plots showing the distribution of the average fixation duration for both Experienced and Novice drivers on Dynamic and Static sign types. There are no significant differences between average durations for each sign type, nor between each driver group.

first fixation times for Static signs ($M = 3487.57$ ms, $SD = 2254.02$) than with Dynamic Signs ($M = 6325.3$, $SD = 3414.96$). Like the ANOVA however, there were no significant effects of Driver Group ($p = .06$), nor any interaction effects ($p = .21$).

The results of the memory recall test indicated that both experienced drivers and novice drivers exhibited better memory retention for dynamic traffic signs compared to static traffic signs. Specifically, experienced drivers achieved an average score of $M = 7.63$ ($SD = 2.08$) for recalling dynamic signs, as opposed to $M = 6.71$ ($SD = 1.82$) for static signs. Novice drivers attained an average score of $M = 7.15$ ($SD = 1.78$) for dynamic signs, in comparison to $M = 6.70$ ($SD = 1.45$) for static signs (see [fig. 15](#)). The 2×2 repeated measure ANOVA showed that there was a significant main effect of sign type, ($F(1, 42) = 5.45$, $p < .05$, $\eta_p^2 = 0.11$). However, no significant interaction was found between memory recall test and driver experience ($F(1, 42) = 0.636$, $p = .429$, $\eta_p^2 = 0.015$). (See [Fig. 16](#).)

4. Discussion

Hypothesis one raised mixed findings in the demographic's response to flood waters. The study found that young drivers are less likely to drive through flood waters. This finding agrees in part with findings from accident fatality data in a Greek ([Diakakis & Deligiannakis, 2013](#)) and an Australian study ([Ahmed et al., 2020](#)), but is contrary to the findings of a US study which found that 18–35 year drivers were more likely to take such risks ([Drobot et al., 2007](#)). Whether this is due to cultural differences, a difference in methodology or a change in time with the US study being significantly older is unclear. However, research shows that the US typically has a lower road safety record than Europe with far higher road fatalities across all variables, population size, vehicle numbers and distance travelled (Luoma and Sivak 2014). There was also a lack of a significance in respect to sex, vehicle type, location and response to flood, which was surprising as it was expected that male respondents ([Ahmed et al., 2020](#); [Diakakis & Deligiannakis, 2013](#); [Hamilton et al., 2018](#); [Haynes et al., 2017](#); [Smith, 2018](#)), drivers of 4×4 vehicles ([Ahmed et al., 2020](#); [Coles, 2008](#); [Gissing et al., 2016](#); [Haynes et al., 2017](#)) and those from rural areas ([Diakakis & Deligiannakis, 2013](#); [Gissing et al., 2019](#)) would be more likely to drive through flood water but this was not found to be the case in our UK study, as neither category showed significance. This difference could be due to the predominately US ([Coles, 2008](#)) and Australian focus ([Ahmed et al., 2020](#); [Gissing et al., 2016](#); [Gissing et al., 2019](#); [Hamilton et al., 2018](#); [Haynes et al., 2017](#)) of existing studies, that represent larger geographical and in particular rural distances and both countries having a higher proportion of 4×4 type vehicles ([International Energy Agency, 2020](#); [Martin, 2023](#)) than the UK. The Greek study ([Diakakis & Deligiannakis, 2013](#)) analysed data from a 40-year period, which affects the ability to compare the findings with the more recent studies. The findings related to hypothesis one suggests that no specific UK driver groups need to be targeted, but that general awareness is needed across the range of UK drivers regardless of demographics.

Hypothesis two questioned whether drivers are less likely to react to flooding 'warning' signage than other mandatory forms of signage such as speed limits. The survey found this was the case, with a stark lack of compliance for the static Flood 'warning sign' when compared to the static 'mandatory' signage tested. This lack of adherence amongst drivers is acknowledged in the international literature concerning static flood signage ([Becker et al., 2015](#); [Gissing et al., 2016](#); [Higgins et al., 2012](#); [Rae et al., 2016](#)) and could be attributed to static flood signs remaining deployed and visible beyond a flood state when the risk has passed, an issue that can be readily addressed in dynamic signage.

Hypothesis Three predicted that drivers would report greater willingness to believe in the dangers presaged by dynamic signs compared to a static sign, which was supported in the survey findings. Driver responses suggest that they would be more likely to seek an alternative route when they encounter a dynamic or hybrid flooding sign when compared to a static flooding sign. Furthermore,

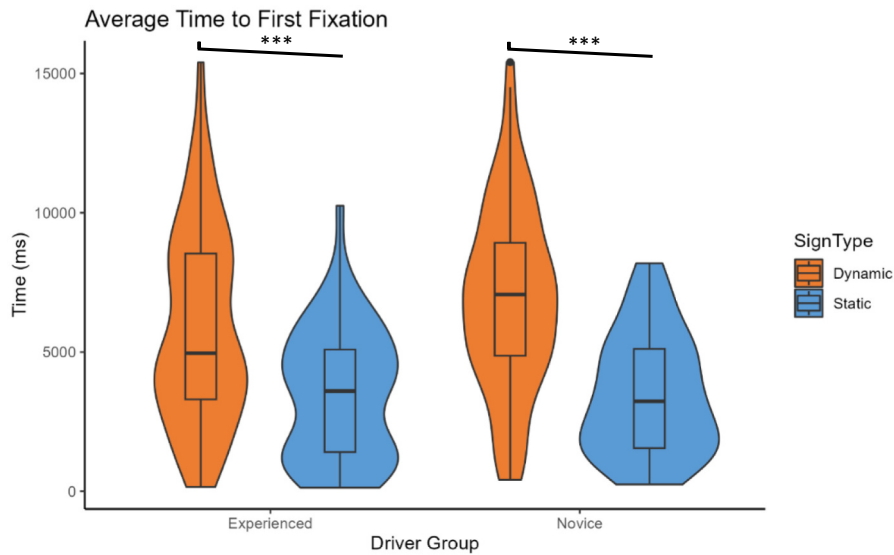


Fig. 15. Average number of signs recalled by driver experience.

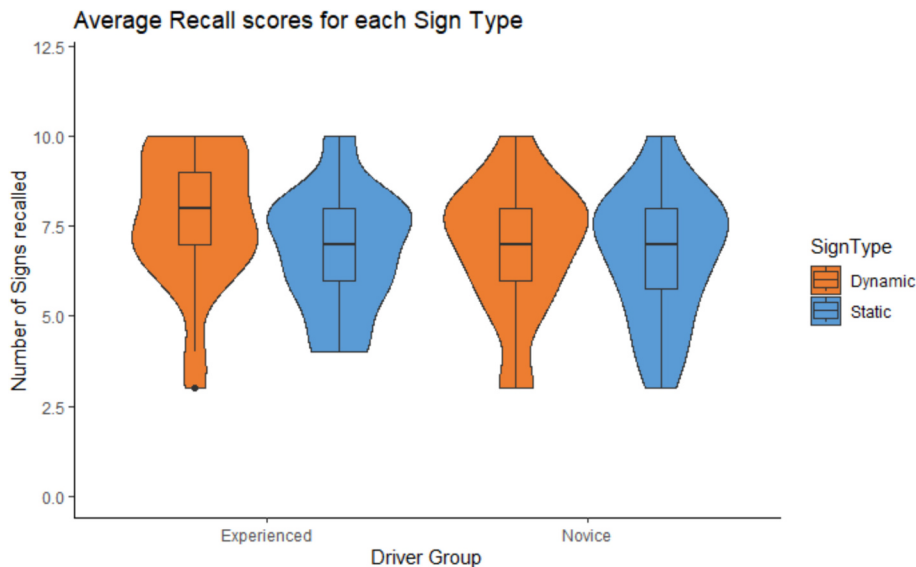


Fig. 16. Violin Plots showing the distribution of the average time to first fixation for both Experienced and Novice drivers on Dynamic and Static sign types. Both driver groups showed significantly faster fixations for Static signs, though there were no differences between driver groups.

correlations between the three sign types comparing the driver's willingness to enter flood water, showed significance when comparing responses for the dynamic and hybrid signs with that of the static sign. This finding when considered in respect to hypothesis two could suggest that the distrust of static signs isn't true of dynamic signs which can be activated to display real time data only and remain off when a flood state isn't present. Hypotheses two and three were therefore tested further experimentally in study two, using eye tracking and memory recall to test the efficacy of dynamic signage compared to static signage.

As hypothesised flooding dynamic signage was found to be demonstrably more effective than the equivalent static forms in agreement with the US flooding literature (Higgins et al., 2012). However, this study finds dynamic signage was consistently more effective across all road signs used in the experiment not only flooding and for all demographics including driving experience. Drivers tended to fixate on Static signs more frequently than Dynamic ones, which is likely as static signs are more familiar to drivers being more commonly seen on the road. However, there was no difference in fixation duration means between the two sign types. This means that dynamic signs are not more distracting than static signage, contrary to previous research into commercial variable message signs that found that shows drivers fixate on electronic advertisements more than standard billboards (Dukic et al., 2013; Perez et al., 2012). In fact, drivers were seemingly slower to fixate on the dynamic signs compared to the static ones. This is likely due to the static sign

prevalence, with their commonality making them more salient to drivers scan patterns. Another potential consideration to explain the lower fixation duration is that static signs are permanently visible, whereas a dynamic sign will typically only illuminate in the presence of a vehicle or required environmental conditions, unlike electronic billboards which are always illuminated. However, for this study the dynamic signs were illuminated for the duration of the eye tracking clip to ensure parity, particularly the dynamic flood sign as flooding conditions were simulated.

The differences in the number of fixations between dynamic and static modes was greater with some signs than others and was significant for static higher speed limit signs such as the 50mph and national speed limit signs. This is an interesting finding and could suggest that static signage is particularly beneficial in higher speed environments or when the sign is common, expected or familiar. However, this is difficult to test in the conditions of this experiment as whilst the video was recorded at speeds appropriate to the road being driven, the element of heightened sensitivity of driving at speed can't be captured due to the static nature of the experiment. Future research to explore the speed effect could be conducted more effectively within a driving simulator.

Of interest only the static 50mph and national speed limit signs showed a statistically significant difference between the number of fixations compared to the dynamic. These were motorway gantry signs that are positioned much higher up than the other standard post-based road signs. Further research exploring impact of motorway gantry signs specifically to investigate this difference would be useful, considering the positioning, nature of use for variable speed signs and impact of speed and road type to determine whether dynamic signs are less effective at higher speeds.

The key finding, however, is that dynamic signage is more memorable with higher recall, despite being fixated upon less. Dynamic signs were found to be no more distracting than static signs, there was no difference in the fixation duration, but drivers were better able to process the dynamic signs as evidenced through their recall despite fixating on them later than static signs. This suggests that dynamic signs are a preferable way to communicate information to drivers, having less of an impact on driver's visual search patterns. Particularly the dynamic flooding sign, which had higher recall and attracted a greater number of fixations than the static flood sign. This is potentially because static flood signs are placed on roads that are prone to flooding being left in situ 24/7, even when the road is no longer flooded (Shah et al., 2018), resulting in drivers distrusting and disregarding their information in most cases. However, dynamic flood signs such as the one developed for this study can be actively controlled so that they only illuminate when there is an actual presence of a flood, and as such are more salient and reliable to drivers.

Combined with the results from Study 1 where drivers reportedly disregarded static flood signs, these results suggest that using Dynamic Flood warnings signs can have a greater impact for drawing the attention of drivers to flooding and thereby lessen the dangers of driving through flood water.

5. Limitations and further work

All research conducted in this study assumed optimal clear daylight conditions for the comparison of signage. However, as noted in the literature the highest percentage of fatal incidents due to flooding occurred in poor visibility in night, twilight conditions or heavy rain conditions (Ahmed et al., 2020; Diakakis & Deligiannakis, 2013; Gissing et al., 2023; Haynes et al., 2017). These are circumstances that are likely to be significantly improved by dynamic forms of signage and therefore this should be the focus of future studies. Furthermore, as noted there were differences in fixations for higher speed limit signage, particularly motorway gantry signs, which would benefit from further research considering sign positioning and consideration of the speed effect which could be conducted more effectively within a driving simulator, but was outside the scope of this study.

6. Conclusions

This paper presents new insights in respect to drivers' knowledge, understanding and response to road flooding in the UK an area of under explored research internationally. Study one built on the existing international literature by demonstrating a lack of understanding amongst the public of the specific risks associated with road flooding. Whilst most respondents highlighted correct depths and water entry speed for flooded roads, there was a disconnect in the critical importance of the water flow rate, which is a key factor in fatal incidents. Furthermore, the driver's perceived ability to pass through flood water were typically based on perceived rather than measured water depth and other driver's reactions to flood, rather than a judgment on the effective water speed or flow rate that could be identified through movement or ripples in the water. The survey also found the respondents' ability to differentiate differences in water depth against roadside objects was also compromised, which is particularly concerning in instances of flash or pluvial flooding that occur in places without water depth gauges like Fords and Bridges do. Existing static flood signage is shown to be ineffective and not fit for purpose, often being dismissed by drivers agreeing with the international literature (Activa, 2014; Ahmed et al., 2020; Gissing et al., 2016; Hamilton et al., 2016). It is suspected that the nature of deployment of static flood signage and how timely such signage is covered or removed after a flooding event creates mistrust. Due to the limitations of its implementation, typically being displayed either permanently in flood prone locations or through the use of temporary or flip-over 'static' signage as recognised in the literature (Higgins et al., 2012; Shah et al., 2018) and anecdotally through our own research when speaking with drivers. This mistrust of static signage could explain the higher willingness amongst respondents in this study to drive through flood water when presented with a static compared to dynamic and hybrid signage. Our research suggests that dynamic flood signage addresses these limitations and is the preferable and more effective option, being borne out in both the results of the survey, eye tracking and memory recall test. Furthermore, dynamic signage is shown to have higher recall across all sign types tested in study 2, compared to their static equivalents.

The results of the survey, eye-tracking and memory recall studies clearly demonstrate that the installation of dynamic signage in

flood prone danger areas is more effective and engaging for motorists and further work will be undertaken to explore the most appropriate graphics (Dewar & Pronin, 2023) and colour (Jing et al., 2017) for communication to maximise its potential further.

This study concerns flooding signage used at a local, regional and national level with implications for future dynamic signage development, deployment and policy. The study also has implications for the future of driver training and instruction, to address the knowledge and judgment gaps around road flooding, recommending that references to road flooding should be included in future revisions of the UK's Highway Code.

CRediT authorship contribution statement

Matthew Watkins: Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Maryam Bathaei Javareshk:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Thomas Goodge:** Writing – review & editing, Visualization, Validation, Formal analysis, Data curation. **James Blundell:** Writing – review & editing, Validation. **David Crundall:** Writing – review & editing, Supervision, Methodology, Formal analysis.

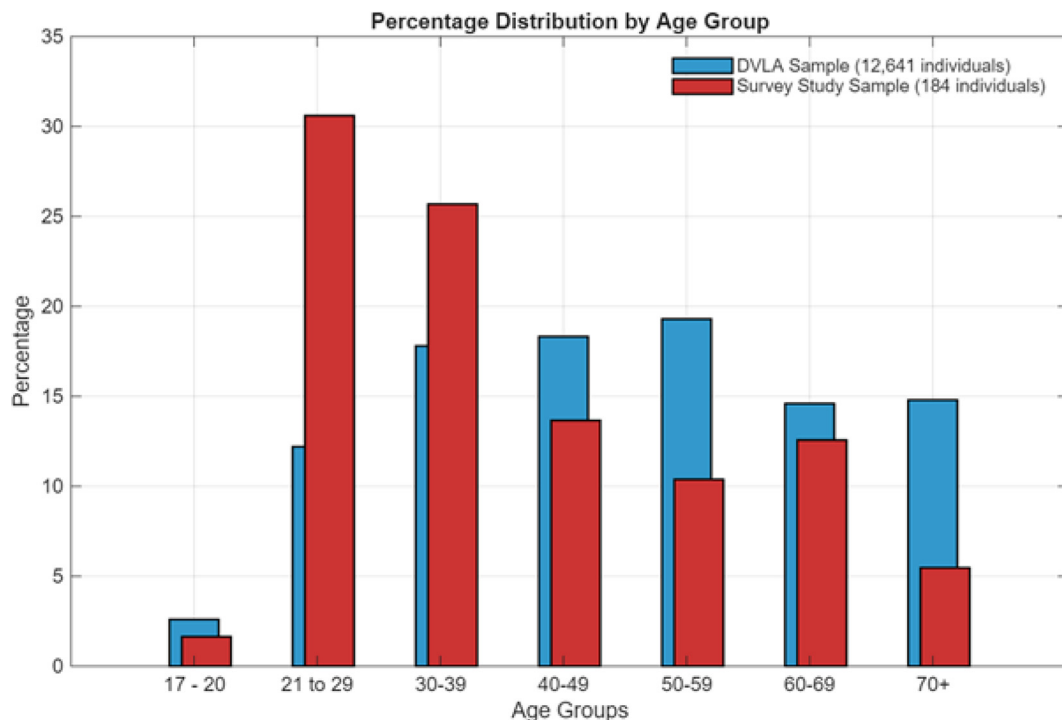
Declaration of competing interest

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.

Acknowledgements

We would like to thank and acknowledge the support given to this project from Via and Nottinghamshire County Council and the technical assistance from Dr. Jillian Labadz, Joseph Meeks, Greg Rolleston, and Paul Watts. This project was funded by the Nottingham Trent University (NTU) Research Commercialisation Fund.

Appendix A



Age representation data Survey data compared to DVLA license holder data for same period.

Appendix B

Correlations between demographic measures and willingness to drive through flood waters. Please note that N changes across the matrix due to missing values in the survey. Significant correlations are reported in bold.

	Age	Driving experience (years' post-license)	Sex	Miles driven per year	Leisure mileage	Car ownership	Car type	Driving in urban area	Driving in suburban area	Driving in rural area	Driving in motorways area
Willingness to drive through flood waters	0.342 <i>p</i> < .001 <i>N</i> = 183	0.276 <i>p</i> < .001 <i>N</i> = 185	−0.055 <i>p</i> = .45 <i>N</i> = 185	0.053 <i>p</i> = .47 <i>N</i> = 185	0.053 <i>p</i> = .47 <i>N</i> = 185	0.028 <i>p</i> = .70 <i>N</i> = 185	0.051 <i>p</i> = .49 <i>N</i> = 185	−0.112 <i>p</i> = .13 <i>N</i> = 185	−0.075 <i>p</i> = .30 <i>N</i> = 185	−0.027 <i>p</i> = .71 <i>N</i> = 185	−0.015 <i>p</i> = .84 <i>N</i> = 185
Age		0.717 <i>p</i> < .001 <i>N</i> = 183	−0.465 <i>p</i> < .001 <i>N</i> = 183	0.062 <i>p</i> = .40 <i>N</i> = 183	0.471 <i>p</i> < .001 <i>N</i> = 183	−0.206 <i>p</i> = .005 <i>N</i> = 183	0.297 <i>p</i> < .001 <i>N</i> = 183	−0.093 <i>p</i> = .21 <i>N</i> = 183	−0.058 <i>p</i> = .43 <i>N</i> = 183	0.125 <i>p</i> = .09 <i>N</i> = 183	−0.123 <i>p</i> = .09 <i>N</i> = 183
Driving experience (years' post-license)			−0.394 <i>p</i> < .001 <i>N</i> = 185	0.169 <i>p</i> = .02 <i>N</i> = 185	0.367 <i>p</i> < .001 <i>N</i> = 185	−0.180 <i>p</i> = .01 <i>N</i> = 185	0.356 <i>p</i> < .001 <i>N</i> = 185	−0.092 <i>p</i> = .21 <i>N</i> = 185	−0.009 <i>p</i> = .90 <i>N</i> = 185	0.052 <i>p</i> = .48 <i>N</i> = 185	−0.110 <i>p</i> = .13 <i>N</i> = 185
Sex				−0.243 <i>p</i> = .001 <i>N</i> = 185	−0.238 <i>p</i> = .001 <i>N</i> = 185	0.202 <i>p</i> = .006 <i>N</i> = 185	−0.333 <i>p</i> < .001 <i>N</i> = 185	0.122 <i>p</i> = .09 <i>N</i> = 185	0.034 <i>p</i> = .64 <i>N</i> = 185	−0.275 <i>p</i> < .001 <i>N</i> = 185	−0.044 <i>p</i> = .54 <i>N</i> = 185
Miles driven per year					0.246 <i>p</i> = .003 <i>N</i> = 185	−0.166 <i>p</i> = .02 <i>N</i> = 185	0.197 <i>p</i> = .001 <i>N</i> = 185	−0.057 <i>p</i> = .44 <i>N</i> = 185	0.040 <i>p</i> = .59 <i>N</i> = 185	0.305 <i>p</i> < .001 <i>N</i> = 185	0.332 <i>p</i> < .001 <i>N</i> = 185
Leisure mileage						−0.164 <i>p</i> = .02 <i>N</i> = 185	0.197 <i>p</i> = .007 <i>N</i> = 185	−0.115 <i>p</i> = .11 <i>N</i> = 185	−0.069 <i>p</i> = .34 <i>N</i> = 185	0.047 <i>p</i> = .52 <i>N</i> = 185	−0.209 <i>p</i> = .004 <i>N</i> = 185
Car ownership							−0.029 <i>p</i> = .69 <i>N</i> = 185	−0.083 <i>p</i> = .26 <i>N</i> = 185	−0.224 <i>p</i> = .002 <i>N</i> = 185	−0.260 <i>p</i> < .001 <i>N</i> = 185	−0.057 <i>p</i> = .44 <i>N</i> = 185
Car type								−0.066 <i>p</i> = .36 <i>N</i> = 185	0.038 <i>p</i> = .60 <i>N</i> = 185	−0.191 <i>p</i> = .009 <i>N</i> = 185	−0.039 <i>p</i> = .59 <i>N</i> = 185
Driving in urban area									0.227 <i>p</i> = .002 <i>N</i> = 185	−0.184 <i>p</i> = .012 <i>N</i> = 185	0.001 <i>p</i> = .99 <i>N</i> = 185
Driving in suburban area										0.133 <i>p</i> = .07 <i>N</i> = 185	−0.055 <i>p</i> = .45 <i>N</i> = 185
Driving in rural area											0.097 <i>p</i> = .18 <i>N</i> = 185

Data availability

Data will be made available on request.

References

- Activa. (2014). AA Warns Drivers to Take Notice of 'Road "Closed" Signs'. Webpage. <https://www.activacontracts.co.uk/news/aa-warns-drivers-to-take-notice-of-road-closed-signs.html> Accessed: 23 July 2020.
- Ahmed, M. A., Haynes, K., & Taylor, M. (2018). Driving into floodwater: A systematic review of risks, behaviour and mitigation. *International Journal of Disaster Risk Reduction*, 31, 953–963. <https://doi.org/10.1016/j.ijdrr.2018.07.007>

- Ahmed, M. A., Haynes, K., & Taylor, M. (2020). Vehicle-related flood fatalities in Australia, 2001–2017. *Journal of Flood Risk Management*, 13(3), Article e12616. <https://doi.org/10.1111/jfr3.12616>
- Bates, D., et al. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, 67(1), 1–48. <https://doi.org/10.18637/jss.v067.i01>
- Becker, J. S., et al. (2015). A Review of People's Behavior in and around Floodwater. *Weather, Climate, and Society*, 7(4), 321–332. <https://doi.org/10.1175/WCAS-D-14-00030.1>
- Burge, M. (2017). *Solar flood signs across Logan City warn drivers about dangerous conditions*, Jimboomba Times. Australia: Logan. <https://www.jimboombatimes.com.au/story/4642726/solar-flood-signs-rise-to-the-challenge/> Accessed: 19 May 2020.
- Coles, A. R. (2008). *Managing Flash Floods: Risk Perception from a Cultural Perspective*. The University of Arizona. Available at: https://repository.arizona.edu/bitstream/10150/632884/1/azu_etd_geog_2008_0001_sip1_m.pdf.
- Crundall, D., & Underwood, G. (2001). The priming function of road signs. *Transportation Research Part F: Traffic Psychology and Behaviour*, 4(3), 187–200. [https://doi.org/10.1016/S1369-8478\(01\)00023-7](https://doi.org/10.1016/S1369-8478(01)00023-7)
- Dewar, R., & Pronin, M. (2023). Designing road sign symbols. *Transportation Research Part F: Traffic Psychology and Behaviour*, 94, 466–491. <https://doi.org/10.1016/j.trf.2022.12.008>
- Diakakis, M., & Deligiannakis, G. (2013). Vehicle-related flood fatalities in Greece. *Environmental Hazards*, 12(3–4), 278–290. <https://doi.org/10.1080/17477891.2013.832651>
- Drobot, S. D., Benight, C., & Grunfest, E. C. (2007). Risk factors for driving into flooded roads. *Environmental Hazards*, 7(3), 227–234. <https://doi.org/10.1016/j.envhaz.2007.07.003>
- Dukic, T., et al. (2013). Effects of Electronic Billboards on Driver Distraction. *Traffic Injury Prevention*, 14(5), 469–476. <https://doi.org/10.1080/15389588.2012.731546>
- Environment Agency. (2019). *Driving complacency: 74% of drivers would risk life in flood water*, GOV.UK. <https://www.gov.uk/government/news/driving-complacency-74-of-drivers-would-risk-life-in-flood-water> Accessed: 22 May 2020.
- Evans, B., et al. (2024). A combined stability function to quantify flood risks to pedestrians and vehicle occupants. *Science of the Total Environment*, 908, Article 168237. <https://doi.org/10.1016/j.scitotenv.2023.168237>
- FitzGerald, G., et al. (2010). Flood fatalities in contemporary Australia (1997–2008). *Emergency Medicine Australasia*, 22(2), 180–186. <https://doi.org/10.1111/j.1742-6723.2010.01284.x>
- Franklin, R., et al. (2014). “Washed away”—assessing community perceptions of flooding and prevention strategies: a North Queensland example. *Natural Hazards: Journal of the International Society for the Prevention and Mitigation of Natural Hazards*, 73(3), 1977–1998. Available at: <https://econpapers.repec.org/RePEc:spr:nathaz:v:73:y:2014:i:3:p:1977-1998>.
- Gissing, A., et al. (2016). Motorist behaviour during the 2015 Shoalhaven floods. *Australian Journal of Emergency Management*, 31(2), 25–30.
- Gissing, A., et al. (2019). Influence of road characteristics on flood fatalities in Australia. *Environmental Hazards*, 18(5), 434–445. <https://doi.org/10.1080/17477891.2019.1609407>
- Gissing, A., et al. (2023). *Vehicle-Related Causes of Flood Fatalities*. Oxford University Press. <https://doi.org/10.1093/acrefore/9780199389407.013.438>
- Hamilton, K., et al. (2016). Stop there's water on the road! Identifying key beliefs guiding people's willingness to drive through flooded waterways. *Safety Science*, 89, 308–314. <https://doi.org/10.1016/j.ssci.2016.07.004>
- Hamilton, K., et al. (2018). Changing people's attitudes and beliefs toward driving through floodwaters: Evaluation of a video infographic. *Transportation Research Part F: Traffic Psychology and Behaviour*, 53, 50–60. <https://doi.org/10.1016/j.trf.2017.12.012>
- Hamilton, K., et al. (2023). Beliefs and attitudes of Australian learner drivers toward driving and avoiding driving through floodwater. *Transportation Research Part F: Traffic Psychology and Behaviour*, 94, 492–503. <https://doi.org/10.1016/j.trf.2023.02.014>
- Hannafoord, J., & Marsh, T. J. (2008). High-flow and flood trends in a network of undisturbed catchments in the UK. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, 28(10), 1325–1338.
- Haynes, K., et al. (2017). Exploring the circumstances surrounding flood fatalities in Australia—1900–2015 and the implications for policy and practice. *Environmental Science & Policy*, 76, 165–176. <https://doi.org/10.1016/j.envsci.2017.07.003>
- Higgins, L., Balke, K., & Chrysler, S. T. (2012). Driver Responses to Signing Treatments for Flooded Roads. *Transportation Research Record*, 2321(1), 98–107. <https://doi.org/10.3141/2321-13>
- Hiramoto, T., et al. (2025). Relationship between vehicle probe data and flooding conditions for developing flood inundation monitoring method. *International Journal of Disaster Risk Reduction*, 120, Article 105373. <https://doi.org/10.1016/j.ijdrr.2025.105373>
- Hoogerbrugge, A. J., et al. (2025). When is enough enough? Empirical guidelines to determine participant sample size for scene viewing studies. *Behaviour Research Methods*, 57(9), 241.
- International Energy Agency. (2020). Share of SUVs in total car sales in key markets, 2010–2019. Available at: <https://www.iea.org/data-and-statistics/charts/share-of-suvs-in-total-car-sales-in-key-markets-2010-2019> Accessed: 1 October 2025.
- Jamson, S., & Mrozek, M. (2017). Is three the magic number? The role of ergonomic principles in cross country comprehension of road traffic signs. *Ergonomics*, 60(7), 1024–1031. <https://doi.org/10.1080/00140139.2016.1245874>
- Jing, F., et al. (2017). Enhancing the effectiveness of flood road gauges with color coding. *Natural Hazards*, 88(1), 55–70. <https://doi.org/10.1007/s11069-017-2856-9>
- Kellar, D. M. M., & Schmidlin, T. W. (2012). Vehicle-related flood deaths in the United States, 1995–2005. *Journal of Flood Risk Management*, 5(2), 153–163. <https://doi.org/10.1111/j.1753-318X.2012.01136.x>
- Kramer, M., Terheiden, K., & Wieprecht, S. (2016). Safety criteria for the trafficability of inundated roads in urban floodings. *International Journal of Disaster Risk Reduction*, 17, 77–84. <https://doi.org/10.1016/j.ijdrr.2016.04.003>
- Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest Package: Tests in Linear Mixed Effects Models. *Journal of Statistical Software*, 82(13 SE-Articles), 1–26. <https://doi.org/10.18637/jss.v082.i13>
- Luck, S. J., et al. (2021). Progress toward resolving the attentional capture debate. *Visual Cognition*, 29(1), 1–21. <https://doi.org/10.1080/13506285.2020.1848949>
- Makowski, D., et al. (2023). *Automated Results Reporting as a Practical Tool to Improve Reproducibility and Methodological Best Practices Adoption*. <https://doi.org/10.32614/CRAN.package.report>
- Martin, P. (2023). *Where did the cars go? How heavier, costlier SUVs and utes took over Australia's roads*. October: The Conversation. Available at: <https://theconversation.com/where-did-the-cars-go-how-heavier-costlier-suvs-and-utes-took-over-australias-roads-215774>.
- Martínez-Gomariz, E., et al. (2017). A new experiments-based methodology to define the stability threshold for any vehicle exposed to flooding. *Urban Water Journal*, 14(9), 930–939. <https://doi.org/10.1080/1573062X.2017.1301501>
- Panakkal, P., & Padgett, J. E. (2024). More eyes on the road: Sensing flooded roads by fusing real-time observations from public data sources. *Reliability Engineering & System Safety*, 251, Article 110368. <https://doi.org/10.1016/j.ress.2024.110368>
- Perez, W. A., et al. (2012). ‘Driver Visual Behavior in the Presence of Commercial Electronic Variable Message Signs (CEVMS)’. Edited by United States: Federal Highway Administration, p. 70. Available at: <https://rosap.nhtl.bts.gov/view/dot/49030>.
- Pregnotat, M., et al. (2017). The impact of flooding on road transport: A depth-disruption function. *Transportation Research Part D: Transport and Environment*, 55, 67–81. <https://doi.org/10.1016/J.TRD.2017.06.020>
- Prosdociimi, I., Kjeldsen, T. R., & Svensson, C. (2014). Non-stationarity in annual and seasonal series of peak flow and precipitation in the UK. *Natural Hazards and Earth System Sciences*, 14(5), 1125–1144.
- Rae, E., et al. (2016). ‘PREVENTING FLOOD RELATED FATALITIES – A FOCUS ON PEOPLE DRIVING THROUGH FLOODWATER’, in *The Bushfire and Natural Hazards CRC & AFAC conference*. Brisbane (pp. 155–177).
- Robins, P. E., & Lewis, M. J. (2019). Changing hydrology: A UK perspective. In *Coasts and Estuaries* (pp. 611–617). Elsevier.

- Sayers, P., Penning-Rowsell, E. C., & Horritt, M. (2018). Flood vulnerability, risk, and social disadvantage: current and future patterns in the UK. *Regional Environmental Change*, 18(2), 339–352.
- Scrimsign. (2020). Flood Warning Signs. https://www.scrimsign.co.uk/Uploads/users/scrimsign/0k4b5fr9cl8c0lkclacq9qhbl1/2014/11/12/7fe4utJl_scrimsign_flood_warning.pdf Accessed: 19 May 2020.
- Shah, S. M. H., et al. (2018). Design considerations of an advanced flood cautionary sign for vehicles safety at low lying areas. *Malaysian Construction Research Journal (MCRJ)*, 4(2), 162–173. Available at: <https://khub.utp.edu.my/scholars/id/eprint/10703>.
- Smith, T. (2018). Driving Into Flood Water – Is It Worth the Risk?, UNDA. Available at: (Accessed: 22 May 2020) <https://www.unda.co.uk/news/driving-flood-water-worth-risk/>.
- Suarez, P., et al. (2005). Impacts of flooding and climate change on urban transportation: A systemwide performance assessment of the Boston Metro Area. *Transportation Research Part D: Transport and Environment*, 10(3), 231–244. <https://doi.org/10.1016/j.trd.2005.04.007>
- The Department for Transport. (2020). *The Highway Code*, GOV.UK. <https://www.gov.uk/guidance/the-highway-code> (Accessed: 22 May 2020).
- Theeuwes, J. (2010). Top-down and bottom-up control of visual selection. *Acta Psychologica*, 135(2), 77–99. <https://doi.org/10.1016/j.actpsy.2010.02.006>
- Versini, P. A., Gaume, E., & Andrieu, H. (2010). Application of a distributed hydrological model to the design of a road inundation warning system for flash flood prone areas. *Natural Hazards and Earth System Sciences*, 10, 805–817.
- Wallingford, H. R., & Flood Hazard Research Centre and Analysts, R. & P. (2006). *R&D OUTPUTS: FLOOD RISKS TO PEOPLE: PHASE 2 FD2321/TR2*, DEFRA/Environmental Agency.
- Wickham, H. (2016). In H. Wickham (Ed.), *Data Analysis BT - ggplot2: Elegant Graphics for Data Analysis* (pp. 189–201). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-24,277-4_9.



DSPACE

<https://dspace.org/>

An investigation into driver's perceptions of road flooding and adherence to signage

Watkins, Matthew; Javareshk, Maryam Bathaei; Goodge, Thomas; Blundell, James; Crundall, David

2026-05

Elsevier

<https://doi.org/10.1016/j.trf.2026.103639>

Watkins M, Javareshk MB, Goodge T, et al., (2026) An investigation into driver's perceptions of road flooding and adherence to signage. Transportation Research Part F: Traffic Psychology and Behaviour, Volume 120, May 2026, Article number 103639