Cross-cultural effects on drivers' use of explicit and implicit communicative cues to predict intentions of other road users

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ABSTRACT

This study explored whether British and Malaysian drivers differ in their use of explicit (turn signals) and implicit (e.g., vehicle position, speed) communicative cues when judging the intention of other road users. Participants viewed videoclips of car drivers and motorcyclists who either continued straight or turned into a junction. The clips terminated immediately prior to any manoeuvre being made and participants were asked to judge whether or not the vehicle would turn. Explicit signals (turn indicators) were manipulated such that valid signals were made 50% of the time. Although both groups of drivers were more accurate on validly signalled trials, British drivers were more affected by signal validity, performing particularly poorly on invalid trials. British drivers were better at judging intentions of cars than motorcycles, whereas Malaysians performed better for motorcycles than cars on invalid trials. We conclude that British drivers heavily rely on explicit signals when judging intention whereas Malaysian drivers are more attuned to implicit signals. Familiarity with vehicle type may also impact performance, especially where cues are ambiguous. Implications for driving abroad and autonomous vehicles are discussed.

1. Introduction

Driving a car involves frequent points of interaction with other road users, during which we both aim to communicate our own behavioural intentions and interpret or predict those of others. These interactions can be highly consequential, as failures to correctly understand or predict another's intended behaviour could result in a collision. For instance, if a driver fails to predict that another vehicle intends to pull out of a parking space (perhaps due to the vehicle driver failing to communicate their intentions clearly), this failure could result in a crash. Recently, road user interactions have been brought into sharp focus in light of developments in driver automation systems and the prospect of perhaps fully automated vehicles (AVs) in the future, as it is widely recognised that interactions with human road users are a key challenge in this area (Rasouli & Tsotsos, 2019; Schieben et al., 2019). AVs will need to both be able to predict what other road users will do, and behave in ways that are predictable by other road users. Therefore, it is essential to understand how human road users communicate their intentions and infer those of others.

It has been proposed that there are two broad types of

communicative behaviour that road users could potentially rely upon to make judgments about another vehicle's intentions, recently defined as implicit and explicit communication (Markkula et al., 2020). Implicit communication refers to aspects of a road user's behaviour that forms part of their execution of the intended movement, but they can be also 'read' by others as a signal or request from that individual. This encompasses behaviours, such as the position, speed, or trajectory of the road user being indicative of intention to yield, or the road user's head or gaze direction indicating that they intend to travel in a particular direction. In contrast, explicit communication refers to behaviour that is not part of the road user's own movements in executing the manoeuvre, but behaviour that can be interpreted by others as a signal or request from that individual. This would include the use of indicators, a horn or bell, and hand signals.

A number of scenarios that are frequently encountered in daily driving involve the use of such communicative behaviours. Previous research has often focused on interactions at junctions, where accidents involving right-of-way violations are relatively common (Clarke et al., 2004; Sarani et al., 2011). Several studies have aimed to determine how drivers use implicit and explicit communicative behaviours to make

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judgments about other road users' intentions at intersections. Understanding how these cues are used and which cue has better accuracy may help explain why right-of-way violations (and associated crashes) occur and could inform targeted interventions for improving road safety. For instance, in a study where car drivers were required to predict the intended manoeuvre of cyclists based on photographs, it was found that drivers were about 80 % accurate when the cyclist made an explicit arm signal, but were more varied in the absence of a signal (Drury & Pietraszewski, 1979), suggesting a heavy reliance on explicit signals.

A more recent study conducted by Lee and Sheppard (2016) evaluated car drivers' judgments of intentions of other cars and motorcycles at junctions using photographs but also video stimuli, which terminated immediately prior to the vehicle's manoeuvre. In this study, explicit and implicit signals were pitted against one another, as the vehicles sometimes used the turn indicator validly (i.e., indicator on when the vehicle turned and indicator off when it did not turn) and sometimes invalidly (e.g., indicator on when the vehicle did not turn and indicator off when it turned). Drivers' judgments were found to be more accurate when signals were valid, suggesting a clear reliance on explicit signals to judge intentions, but they were still systematically accurate with an invalid signal, underlining that drivers also used a range of implicit cues to guide their judgments, especially for the video stimuli. It was also found that judgments were more accurate for cars than motorcycles in the video clips, which the authors argued might be the result of implicit cues, such as movement and position on the road, being more obvious due to their larger size.

Although studies such as these imply that drivers take into account a range of explicit and implicit communicative behaviours to judge other road users' intentions, there is increasing recognition that many aspects of road users' behaviour, including their communicative behaviour, may differ cross-culturally (e.g., Lee et al., 2015; 2020; Lim et al., 2013; 2014; Ventsislavova et al., 2019). This difference could have implications for both the manner and success with which road users in different countries are able to infer others' intentions, which might in turn impact on road safety in the respective countries.

One relevant area of cross-cultural difference is the use of explicit signals of the road users' intentions, and specifically, turn indicator use. For instance, both anecdotal reports (Hessler, 2010) and empirical studies (Zhang et al., 2006) suggest that drivers in China do not routinely use their indicators. In Malaysia, motorcyclists are reported as only using their turn signals on around 40 % of occasions when they should (Ariffin et al., 2020). In contrast, studies that have examined use of turn indicators at intersections have reported relatively high use of these signals by drivers in Canada and the US (around 75 % of the time; Faw, 2013; Sullivan et al., 2015). Whether road users reliably use indicators to communicate their intentions might then affect the extent to which other road users take account of this cue when judging their intended behaviour.

Another relevant area of cross-cultural difference is in road traffic composition. In most western countries, cars make up the bulk of the road traffic, but this is typically not the case in developing countries, where motorised two-wheel vehicles are often predominant (Haworth, 2012). These differences might impact the way that road users judge others' intentions, as certain types of communicative behaviour may only be available for some types of road users, or more salient for some than others. For instance, gaze and/or head direction might be a useful cue for judging the intentions of cyclists or motorcyclists, but is often obscured for car drivers. Road users driving in environments where it is necessary to interact with large numbers of two-wheeled vehicles might therefore have learned to rely on head/gaze position more than those with little exposure to such vehicles.

Moreover, these two areas of cross-cultural variability (i.e., reliable signal use and road traffic composition) might not be independent of one another. A recent study conducted in Vietnam found that whereas car drivers making a turn at an intersection used their turn indicators approximately 68 % of the time, motorcyclists only used their indicators

around 40 % of the time (Nguyen-Phuoc et al., 2019). If other road users are sensitive to this divergence, they might adapt which communicative acts they use to judge others' intentions depending on the vehicle type.

The current study adapted the methodology of Lee and Sheppard (2016) to investigate cross-cultural effects on drivers' judgments about the intentions of other road users in British and Malaysian adults. The two countries share similar driving rules and a left-hand driving environment. However, motorcycles are much more common in Malaysia than in the UK (14.9 million versus 1.3 million in 2020; Asean-StatsDataPortal, 2022; Department for Transport, 2022). Moreover, Malaysian road users have been reported to not use their turn indicator consistently (Abdul Manan & Várhelyi, 2015). Drivers from the two countries viewed short video clips, filmed on British and Malaysian roads, of car drivers and motorcyclists approaching a junction along a main road. In each clip, the vehicle had either continued driving straight or turned into the junction, but the videos terminated immediately prior to any manoeuvre taking place. Participants were required to predict whether each vehicle would continue straight or turn. In half of the videos, the vehicle had its turn indicator on, whereas on the other half, it had not; however, following Lee and Sheppard (2016), this was not predictive of the actual manoeuvre.

It was hypothesised that 1) drivers from both countries would overall be systematically accurate at predicting other road users' intentions (Lee & Sheppard, 2016); 2) drivers would be more accurate when the vehicle made a valid signal (i.e., turn with indicator on or go straight with indicator off) than an invalid signal (i.e., turn with indicator off or go straight with indicator on; Lee & Sheppard, 2016); 3) given that Malaysian road users may not use turn indicators reliably (Abdul Manan & Várhelyi, 2015), the effect of signal validity would be greater for British drivers than Malaysian drivers; 4) drivers would be more accurate at predicting the intentions of cars than motorcycles (Lee & Sheppard, 2016); 5) given that motorcycles are less frequently encountered in the UK than Malaysia (AseanStatsDataPortal, 2022; Department for Transport, 2022), the effect of vehicle type would be greater for British drivers than Malaysian drivers.

2. Method

2.1. Participants

In total, 183 participants were recruited: 83 from the UK (7 males, 75 females, 1 other) and 100 from Malaysia (20 males, 78 females, 2 other). Participants were all students, mostly studying for degrees at the University of Nottingham, at either the UK Campus or the Malaysia Campus. The mean age of British participants was 19.22 years (standard deviation, $SD = 2.50$) ranging from 18 to 35 years and they reported an average of 1.80 years ($SD = 2.44$) of active driving experience since getting their driving license in the UK, ranging from 0 to 20 years. For Malaysian participants, the mean age was 20.77 years ($SD = 2.19$) ranging from 18 to 29 years and they reported an average of 2.51 years ($SD = 2.13$) of active driving experience since getting their driving license in Malaysia, ranging from 0 to 11 years. All participants reported normal or corrected-to-normal vision and were not colour blind. They reported no experience of riding a motorcycle.

2.2. Design

A $2 \times 2 \times 2$ mixed design was used. There were two within-subjects independent variables: type of approaching vehicle (car or motorcycle) and signal validity (valid or invalid). Nationality of the participant (British or Malaysian) was the between-subjects independent variable. The valid signal condition included trials where the approaching vehicle was turning with the turn indicator on or going straight with the turn indicator off. The invalid signal condition included trials where the approaching vehicle was turning with the turn indicator off, or going straight with the turn indicator on. The dependent variable was the

accuracy of participants' judgments about the intended manoeuvre of the approaching vehicles (i.e., turn or driving straight).

Ninety-six trials were presented across two 48-trial blocks, one of which presented videos filmed in the UK and the other presented videos filmed in Malaysia. Stimuli were filmed in both countries to ensure that no group was disadvantaged due to lack of familiarity with the road environments within the stimuli. Each block included 16 stimuli which were repeated three times each. The stimuli were repeated to obtain a more reliable measure of accuracy than if each stimulus was shown only once. The number of repeats was chosen to keep the total study length to around 30 min. These 16 stimuli included two different approaching vehicles (car or motorcycle) which were either turning into the junction or driving straight, with or without the turn indicator on, and were each recorded at two different junctions. All participants took part in both the British and Malaysian blocks, the order of which was counterbalanced for both groups.

2.3. Stimuli

2.3.1. Video recording

The Malaysian videos used in this study were the same ones used in Lee and Sheppard (2016). These were filmed at two junctions near - the University of Nottingham Malaysia (Semenyih and Broga). For the UK stimuli, new videos were filmed according to the same principles at two junctions in Wrexham. Videos of approaching vehicles were recorded from the viewpoint of a driver who was looking straight down the main road (Fig. 1: position A). In Malaysia, a Panasonic HDC-SD900 video camera was used, and in the UK, a Sony Handycam DCR-SX30 was used. The approaching vehicles (which were a silver Toyota Vios and a black Honda PCX 150 motorcycle in Malaysia and a black BMW Series One and a black BMW 1200 GS motorcycle in the UK) travelled in the opposite direction along the road towards the camera position (Fig. 1: position B) at a constant speed (40 km/hour or 25 miles/hour). The approaching vehicle either continued driving straight (Fig. 1: position C) or turned into the junction (Fig. 1: position D) in front of the video camera. Trials were recorded for each of these actions with and without the turn indicator switched on. The car driver and motorcyclist were both male in Malaysia whereas there was a female car driver and a male motorcyclist in the UK. They were instructed to drive or ride as naturally as possible during the video recording. The motorcyclist was wearing a white *t*-shirt with a black jumper and a black helmet in Malaysia, whereas the motorcyclist was wearing a black jumper and a white helmet in the UK (see Fig. 2 for example stimuli).
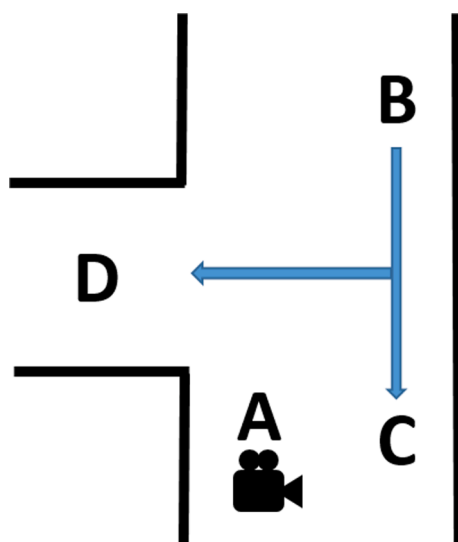

Fig. 1. Initial location of approaching vehicle (B) which either travelled straight (to C) or turned into the junction (to D) and video camera (A).

2.3.2. Video editing

Windows Live Movie Maker was used as the video editor. Each video was edited to create a stimulus lasting 2000 ms. 'Turn' stimuli were created first such that each video was cut off immediately prior to the point at which the wheels of the approaching vehicle started to turn. Then, the 'no turn' stimuli were edited such that the approaching vehicle was at the same distance from the junction as in the corresponding 'turn' stimulus in the final frame of the videos. All the stimuli were presented at a resolution of 854 × 480 pixels.

2.4. Procedure

The study was conducted in Qualtrics, which is an online survey presentation platform, where the information sheet and consent form were first presented. Participants then completed a series of demographic questions (e.g., age, gender, nationality, driving experience). The links of the two experimental blocks were also embedded in Qualtrics. They were first programmed using PsychoPy (Peirce, 2007), and then uploaded to Pavlovia (https://pavlovia.org) which is an online experimental platform.

In the experiment, participants were instructed that they would be presented with a series of videos containing a vehicle that was approaching from the opposite direction while they were driving on the main roadway. On each trial, the trial number was presented for 1000 ms, followed by a fixation cross that was presented for 1000 ms prior to the video itself which lasted 2000 ms. After each video, participants saw a prompt screen detailing which keys to press to give their response. They were advised to judge whether the approaching vehicles intended to continue going straight (by pressing 0 on the numerical keypad) or turn into the junction (by pressing 2 on the numerical keypad). Participants were asked to make their decision as quickly as possible when prompted, although no time limit was imposed. No feedback was given on the accuracy of their responses. All participants participated in two blocks (UK and Malaysia), the order of which was counterbalanced. All stimuli were presented in random sequence within each block and a self-paced break was allowed between the blocks. The experiment took approximately 30 min to complete.

2.5. Analyses

Following Lee and Sheppard (2016), a signal detection coding was used in this experiment. Data were reclassified as 'hits', 'misses', 'false alarms' and 'correct rejections' as shown in Table 1.

Analyses focused on two key metrics: *d' (perceptual sensitivity),* which was used as a measure of drivers' accuracy in predictions for the different conditions; and C *(response criterion),* which was used as a measure of underlying biases in making particular responses (e.g., judging 'turn' too frequently in a particular condition). These metrics were calculated following Macmillan and Creelman (1991), with the log linear correction (Snodgrass & Corwin, 1988). We operationalised the hit rate for a particular condition as being equal to the number of trials on which the participant correctly stated that the vehicle turned in that condition divided by the total number of trials on which the vehicle actually did turn in that condition, which was always 6 (3 repeats of stimulus × 2 junctions). The false alarm rate for a condition was equal to the number of trials on which the participant said "turn" when the vehicle did not turn in that condition, divided by the total number of trials on which the vehicle really did not turn in that condition, which was always 6. *d' is* equal to the z-score of the hit rate minus the z-score of the false alarm rate. Therefore, *d'* is a measure of participants' ability to discriminate between the two trial outcomes (turn and no turn) for each condition. C, on the other hand, is equal to −0.5 multiplied by the sum of the z-score of the hit rate and the z-score of the false alarm rate. This reflects drivers' overall tendency to make a particular response in a particular condition regardless of its accuracy; in this case, whether drivers tend to judge 'turn' too frequently, resulting in values below 0, or

Fig. 2. (a) An approaching motorcycle was turning with the turn indicator on filmed in Malaysia. (b) An approaching motorcycle was going straight with the turn indicator on filmed in the UK. (c) An approaching car was going straight with the turn indicator on filmed in Malaysia. (d) An approaching car was turning with the turn indicator on filmed in the UK.

Table 1
Coding of drivers' responses.

Actual Manoeuvre	Drivers' Response	
	Straight	Turn
Straight	Correct Rejections	False Alarms
Turn	Misses	Hits

'straight' too frequently resulting in values above 0. As the UK and Malaysian stimuli were presented in separate blocks, d' and C were initially calculated separately for each block (UK and Malaysia) but the means of these values were used in subsequent analyses.

Independent-samples t-tests indicated that the Malaysian participants were significantly older, $t(181) = 4.31, p < .001, d = 0.64$, and had significantly more driving experience than the British participants, $t(181) = 2.11, p = .018, d = 0.31$. Although driving experience did not significantly correlate with either mean d' ($r = 0.053, N = 183, p = .48$) or C ($r = 0.095, N = 183, p = .18$), in light of the group differences, driving experience was entered as a covariate in all analyses. Note that due to the high correlation between experience and age in the sample,

only one variable was entered as a covariate and driving experience was chosen over age due to its greater theoretical relevance to task performance.

Pre-analysis checks revealed that the d's were not normally distributed (Shapiro-Wilk $p < .001$) and some could not be normalised via transformation. Some variables also violated tests of homogeneity of variances (Levene's test $p < .001$ for valid and invalid motorcycle trials). Likewise most C were not normally distributed (Shapiro-Wilk $p < .05$) and homogeneity of variance was violated for valid motorcycle trials (Levene's test $p < .001$). Due to the complexity of the multifactorial design and predicted interactions, and ANOVA's robustness to such violations (e.g., Blanca Mena et al., 2017), the main analyses were conducted using ANOVA. However, all key comparisons were repeated using non-parametric equivalents, which confirmed the same pattern of findings in all cases (see Supplementary Information S1 for full details).

One-sample t-tests compared mean d' scores with chance (0) to determine whether participants were significantly accurate in the task in each condition. One-sample t-tests were also conducted to compare C scores with chance (0) to determine whether participants showed significant bias in their judgments. In both cases, an adjusted alpha level of 0.00625 was used due to there being multiple comparisons (8 in total).

To determine whether there were differences in accuracy between the two nationalities and between conditions, a mixed $2 \times 2 \times 2$ ANCOVA was conducted on *d'*, with signal validity (valid or invalid) and vehicle type (car or motorcycle) as within-participants factors, nationality (British or Malaysian) as the between-participants factor, and driving experience as the covariate. A mixed ANCOVA with the same variables included was also used to determine whether there were differences in C between the two nationalities and between conditions. The alpha level for the ANCOVAs was 0.05. Cohen's *d* was calculated as a measure of effect size for t-tests, where 0.20 can be considered to be a small effect, 0.50 is a medium effect, and 0.80 can be considered to be a large effect (Cohen, 1988). For the ANCOVAs, partial eta squared (η_p^2) is reported, whereby 0.01 can be considered to be a small effect, 0.06 is a medium effect, and 0.14 indicates a large effect (Cohen, 1988).

3. Results

3.1. Perceptual sensitivity d'

Table 2 displays the mean *d'* and associated standard deviations for each group in each condition (see Table S2, Supplementary Information for hits, false alarms, misses and correct rejections per condition). Mean *d'* exceeded 0 for both British and Malaysian participants in all conditions (all $p < .00625$).

There was a main effect of vehicle type, $F(1,180) = 86.65$, $p < .001$, $\eta_p^2 = 0.33$, whereby the intentions of cars ($M = 2.05$, $SD = 0.72$) were judged more accurately than intentions of motorcycles ($M = 1.78$, $SD = 0.67$). There was also a main effect of validity, $F(1,18) = 185.37$, $p < .001$, $\eta_p^2 = 0.51$, whereby participants were more accurate at judging the intended manoeuvre when a valid signal ($M = 2.57$, $SD = 0.33$) was made than an invalid signal was made ($M = 1.26$, $SD = 1.29$). Vehicle type and validity interacted, $F(1,180) = 8.91$, $p = .003$, $\eta_p^2 = 0.05$, see Fig. 3. Participants judged cars more accurately than motorcycles on valid trials, $t(182) = 11.38$, $p < .001$, $d = 1.08$, but there was no effect of vehicle type on invalid trials.

There was also a main effect of nationality, $F(1,180) = 22.68$, $p < .001$, $\eta_p^2 = 0.11$ with Malaysians ($M = 2.12$, $SD = 0.60$) being overall more accurate in judging the manoeuvre of other vehicles than British participants ($M = 1.67$, $SD = 0.67$). This was qualified by two further interactions, the first being a validity × nationality interaction, $F(1,180) = 70.04$, $p < .001$, $\eta_p^2 = 0.28$, see Fig. 4. British participants ($M = 2.71$, $SD = 0.30$) were more accurate than Malaysians ($M = 2.46$, $SD = 0.30$) on valid trials, $t(182) = 5.75$, $p < .001$, $d = 0.85$. However, Malaysian participants ($M = 1.79$, $SD = 0.99$) were more accurate than British participants ($M = 0.62$, $SD = 1.33$) on invalid trials, $t(182) = 6.66$, $p < .001$, $d = 0.85$. To specifically address the prediction that the effect of validity would be larger for British than Malaysian participants, difference scores were created by subtracting the mean *d'* for invalid trials from the mean *d'* for valid trials yielding an index of the validity effect. The mean effect of validity was higher for British ($M = 2.10$, $SD = 1.37$) than Malaysian participants ($M = 0.67$, $SD = 0.82$), $t(181) = 8.33$, $p < .001$, $d = 1.24$.

There was no interaction between vehicle type and nationality. However, there was a significant three-way interaction between vehicle type, validity, and nationality, $F(1,180) = 68.85$, $p < .001$, $\eta_p^2 = 0.28$, see Fig. 5. Participants were more accurate at judging cars than motorcycles
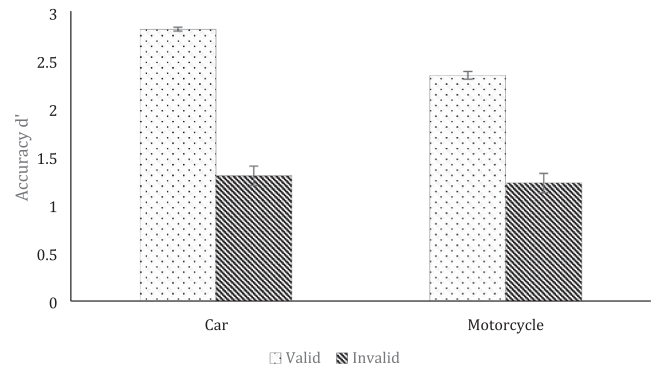

Fig. 3. D' for judging the intention of approaching cars and motorcycles with a valid or an invalid signal (error bars depict between-subjects standard error of the mean).
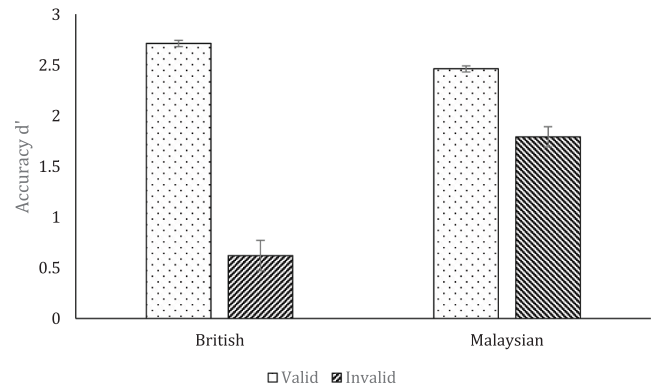

Fig. 4. D' for judging the intention of approaching vehicles with a valid or an invalid signal by british and malaysian participants (error bars depict between-subjects standard error of the mean).
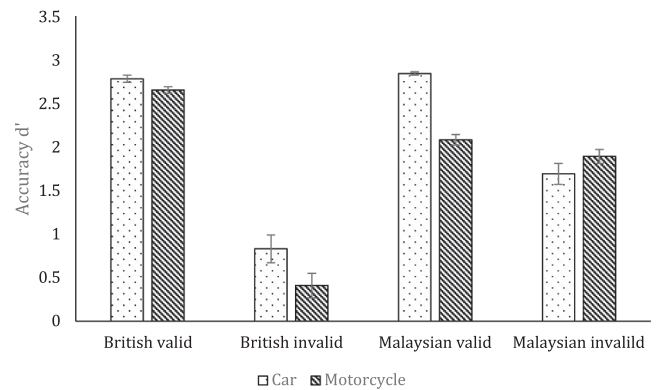

Fig. 5. D' for judging the intention of approaching cars and motorcycles with a valid or an invalid signal by british and malaysian participants (error bars depict between-subjects standard error of the mean).

across all conditions apart from Malaysians on invalid trials, who were more accurate at judging motorcycles than cars, $t(99) = 2.76$, $p = .007$, $d = 0.17$. The effect of vehicle type was greater for Malaysian ($M = 0.76$, $SD = 0.56$) than British participants ($M = 0.13$, $SD = 0.34$) on valid trials, $t(181) = 9.32$, $p < .001$, $d = 1.39$, but greater for British ($M = 0.42$, $SD = 0.67$) than Malaysian participants ($M = -0.21$, $SD = 0.75$) on invalid trials, $t(181) = 5.86$, $p < .001$, $d = 0.87$.

Table 2
Mean (M) and Standard Deviation (SD) of d' for each group in each condition.

	Car				Motorcycle			
	Valid		Invalid		Valid		Invalid	
	M	SD	M	SD	M	SD	M	SD
British	2.78	0.33	0.83	1.45	2.65	0.36	0.41	1.29
Malaysian	2.84	0.19	1.69	1.24	2.08	0.55	1.89	0.83

3.2. Response criterion C

Table 3 displays the mean response criterion C and associated standard deviations for each group in each condition. For valid trials, C was no different from 0 in any condition. For invalid trials, for British participants, C was significantly below 0 for both cars, $t(82) = 10.86$, $p < .001$, $d = 1.19$, and motorcycles, $t(82) = 9.21$, $p < .001$, $d = 1.01$. For Malaysian participants, C was significantly below 0 for cars only, $t(99) = 6.26$, $p < .001$, $d = 0.63$.

There was a main effect of vehicle type, $F(1,180) = 10.74$ $p < .001$, $\eta_p^2 = 0.06$, whereby C was lower for cars ($M = -0.12$, $SD = 0.21$) than for motorcycles ($M = -0.04$, $SD = 0.24$). There was also a main effect of validity, $F(1,180) = 96.81$, $p < .001$, $\eta_p^2 = 0.35$, whereby C was lower for invalidly signalled trials ($M = -0.16$, $SD = 0.31$) than for validly signalled trials ($M = 0.00$, $SD = 0.14$). Vehicle type and validity interacted, $F(1,180) = 8.26$, $p = .005$, $\eta_p^2 = 0.04$, see Fig. 6. C did not differ for cars and motorcycles on valid trials but was lower for cars than motorcycles on invalid trials, $t(182) = 4.78$ $p < .001$, $d = 0.31$.

There was a main effect of nationality, $F(1,180) = 22.24$, $p < .001$, $\eta_p^2 = 0.11$. C was lower for British participants ($M = -0.21$, $SD = 0.18$) than Malaysian participants ($M = -0.08$, $SD = 0.21$). Nationality also interacted with validity, $F(1,180) = 24.27$, $p < .001$, $\eta_p^2 = 0.12$, see Fig. 7. There were no group differences in C on valid trials, but C was lower for British participants ($M = -0.41$, $SD = 0.33$) than Malaysian participants ($M = -0.16$, $SD = 0.31$) on invalid trials, $t(182) = 5.17$, $p < .001$, $d = 0.77$.

Finally, there was a vehicle type by nationality interaction, $F(1,180) = 6.38$, $p = .012$, $\eta_p^2 = 0.03$, see Fig. 8. British participants did not differ in C for cars and motorcycles; Malaysian participants, however, had significantly lower C for cars ($M = -0.12$, $SD = 0.21$) than motorcycles ($M = -0.04$, $SD = 0.24$), $t(99) = 4.66$, $p < .001$, $d = 0.38$. There was no three-way interaction.

4. Discussion

The study reported here tested five predictions in relation to British and Malaysian car drivers' abilities to predict the intentions of other road users at *T*-junctions. In line with previous research (Drury & Pietraszewski, 1979; Lee & Sheppard, 2016) and consistent with Hypothesis 1, the study found that across all conditions, drivers were able to systematically discriminate between trials where the other road user intended to turn into the junction and those when the intention was to continue straight. This finding demonstrates that overall drivers are good at picking up on cues that reliably signal other road users' intentions prior to a manoeuvre being executed, even when information is conflicting or misleading (e.g., when an invalid signal is made).

Nevertheless, against this backdrop of systematically accurate performance, there was a number of clear differences across conditions and driver groups which will now be discussed in relation to the other four hypotheses. In line with Hypothesis 2, drivers were more accurate when a valid signal was given than when an invalid signal was used. This finding is consistent with previous research (Lee & Sheppard, 2016) and demonstrates that it is clearly advantageous across contexts for road users to give a valid signal of their intentions as drivers are more likely to misperceive them if they do not.

The third hypothesis proposed that the effect of signal validity would
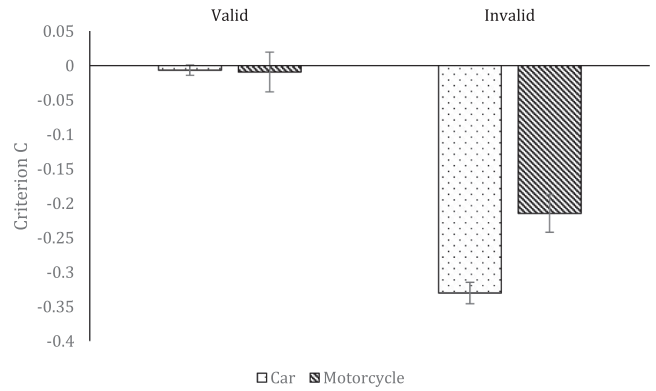

Fig. 6. C for judging the intention of approaching cars and motorcycles with a valid or an invalid signal (error bars depict between-subjects standard error of the mean). A positive C indicates a tendency to say "straight" too much, and a negative C indicates a tendency to say "turn" too much.
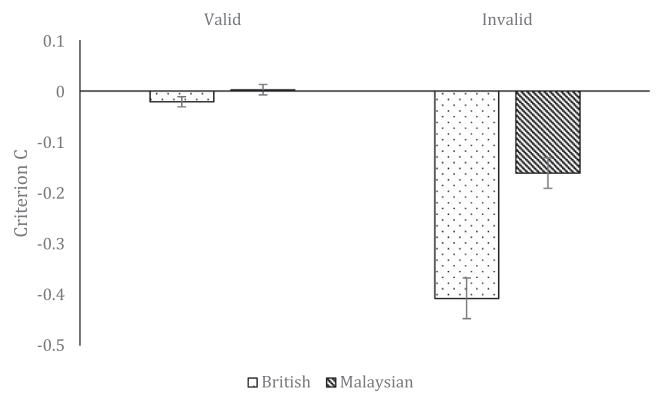

Fig. 7. C for judging the intention of approaching vehicles with a valid or an invalid signal by British and Malaysian participants (error bars depict between-subjects standard error of the mean). A positive C indicates a tendency to say "straight" too much, and a negative C indicates a tendency to say "turn" too much.

be greater for British than Malaysian drivers. The results yielded strong support for this prediction, whereby the difference between valid and invalid trials was significantly higher for British than Malaysian drivers. In fact, close inspection revealed a crossover interaction where British drivers slightly outperformed Malaysians on validly signalled trials but Malaysians performed much better than British drivers on invalidly signalled trials, resulting in an overall advantage in accuracy for the Malaysians. The findings are in line with the notion that British drivers are highly reliant on explicit communication (i.e., turn indicator being on or off) for making their judgments about other road users' intentions, whereas Malaysians may give greater weight to implicit cues, particularly in situations of ambiguity (where the explicit and implicit signals are in conflict with one another).

The fourth hypothesis was that drivers would be more accurate at judging the intentions of cars than motorcycles, and again we found overall support for this prediction, evidenced by a main effect of vehicle
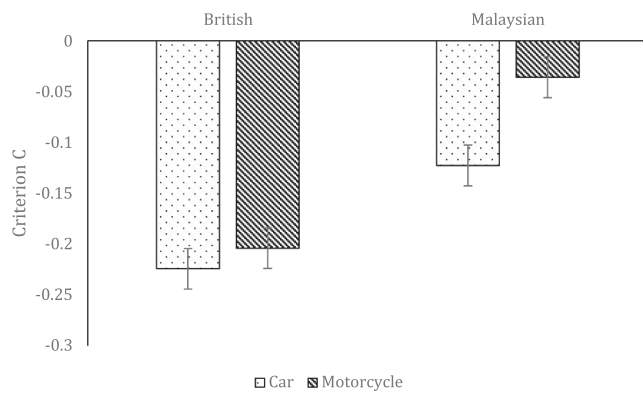
Table 3
Mean and Standard Deviations of C for each group in each condition.

| | Car | | | | Motorcycle | | | |
| | Valid | | Invalid | | Valid | | Invalid | |
	M	SD	M	SD	M	SD	M	SD
British	−0.01	0.12	−0.44	0.37	−0.03	0.15	−0.38	0.37
Malaysian	0.00	0.09	−0.24	0.39	0.01	0.25	−0.08	0.31

Fig. 8. C for judging the intention of approaching cars and motorcycles by British and Malaysian participants (error bars depict between-subjects standard error of the mean). A positive C indicates a tendency to say "straight" too much, and a negative C indicates a tendency to say "turn" too much.

type. This finding replicated the results of Lee and Sheppard (2016) who also found an advantage in accuracy for cars over motorcycles for video stimuli. The authors suggested that this advantage may be because cars are larger in size than motorcycles, hence the various cues to intention (both explicit and implicit) may be easier to perceive for cars. This greater availability of cues should result in higher accuracy levels, at least where the cues are not conflicting.

The fifth hypothesis was that the effect of vehicle type would be greater for British than Malaysian drivers. This prediction was not fully supported, but more nuanced differences were found between the two nationalities for the effects of vehicle type. When a valid signal was made, Malaysian drivers showed a greater effect of vehicle type than British drivers; however, when the signal was invalid, British drivers showed a larger effect of vehicle type than Malaysian drivers. These findings appear to be consistent with British drivers being highly reliant on explicit signals to intention, as well as having low familiarity with implicit cues to intention for motorcycles in particular. Therefore, on valid trials British drivers do not show strong effects of vehicle type because relying on explicit cues would lead to performance around ceiling for both vehicle types. On invalid trials, the lack of familiarity of British drivers with implicit cues to intention for motorcyclists could explain the particularly poor performance in this condition.

Contrary to expectation, Malaysian drivers showed an advantage in judging the intended manoeuvre of motorcycles over cars for invalid trials. This finding could reflect the different kinds of implicit cues available when judging behaviour of motorcycles versus cars. For instance, the motorcycle tilts when about to turn and motorcyclists will tend to turn their heads and gaze into the junction when turning, whereas cars do not tilt and the driver's head and face is often obscured from view. Moreover, it may be the case that motorcyclists use their indicators less frequently than car drivers in Malaysia. Although there is no published study on this topic to our knowledge, lesser use of turn indicators by motorcyclists than car drivers has been reported in another South East Asian country, Vietnam (Nguyen-Phuoc et al., 2019). If Malaysian motorcyclists do not routinely use their indicators, then Malaysian drivers may have become particularly adept at interpreting the other cues to their intentions.

In addition to examining accuracy, response criterion (C) was analysed to give an indication of drivers' strategy when making their judgments. Findings replicated previous research (Lee & Sheppard, 2016) in showing that when a valid signal was made, drivers were not biased towards judging that the other road user would turn or continue straight. However, when an invalid signal was made, in all but one condition, drivers were biased towards judging the vehicle would turn (regardless of being correct or not). As has been argued previously, this response bias may reflect the relative severity of consequences of

inaccurately judging straight or turn. If a driver believes a vehicle will turn but it in fact does not, then this belief has little effect other than perhaps causing the driver to momentarily slow down unnecessarily. On the other hand, judging that a vehicle will go straight when it is actually going to turn risks a collision. Hence, drivers may have a tendency judge 'turn' if there are any cues present that indicate the vehicle may turn. In the case of invalid trials, this tendency would result in a bias towards judging 'turn' over 'straight'. Alternatively (or additionally), this asymmetry could reflect differences in the real-world likelihood of each event. It is probably more common for a vehicle to not indicate when turning than to indicate while continuing straight. This asymmetry might result in drivers being particularly disinclined to judge that the vehicle will go straight when the indicator is on, which would lead to a bias towards turn judgments overall.

There were also some group differences in response criterion. British drivers were more likely to judge the other vehicle was going to turn than Malaysian drivers, and this tendency was specifically the case on invalid trials. This difference might relate to the fact that Malaysian drivers were overall more competent at accurately differentiating between 'turn' and 'straight' trials when the signal was invalid (as evidenced by higher d-primes), but also appears indicative of an overall more cautious strategy adopted by the British participants. This cautious strategy aligns with findings of previous studies that have found that Malaysian drivers are more likely to say they would pull out in front of approaching vehicles at junctions than British drivers (Lee et al., 2015), and show reduced sensitivity to driving hazards (Lim et al., 2013; 2014). Taken together, these findings paint a picture of driving style that involves a higher level of risk in Malaysia, which may contribute to the higher fatality rates on the roads in Malaysia than in the UK (in 2019, the driving fatality rate was 1 in 5,286 in Malaysia versus 1 in 36,947 in the UK; Ministry of Transport Malaysia, 2022; International Transport Forum, 2020).

Response criterion was also lower for cars than motorcycles, and this effect was stronger for Malaysian than British participants. It may be that drivers are more conservative when judging the manoeuvre of cars than motorcycles due to the greater risk to the driver themself when making an inaccurate 'straight' judgment (although the risk to the other road user is greater when an error is made in relation to motorcycles).

4.1. Implications, limitations, and future directions

This study demonstrates striking cross-cultural differences in the way that drivers judge the intentions of approaching vehicles at junctions. First and foremost, the results appear consistent with British drivers showing a greater reliance on explicit signals (i.e., turn indicators) when predicting the behaviour of other road users, whereas Malaysian drivers show a greater reliance on implicit cues (such as vehicle position and movement, or gaze direction). Although the results obtained here appear to show an overall Malaysian advantage in accuracy, it is important to acknowledge that this advantage is likely the consequence of the study design where explicit signals were not predictive of drivers' intentions overall (as 50 % of trials were invalid), whereas implicit signals were present but not manipulated. Therefore, it is possible or perhaps even likely that if we would have conducted the study with explicit signals being 100 % predictive, British drivers may have been equally if not more accurate than Malaysian drivers.

Instead of focusing on relative levels of accuracy, we interpret our findings as evidence that drivers' judgments are impacted by their prior experience or knowledge of the behaviour of other road users. This effect could be seen as an adaptive mechanism whereby drivers preferentially attend to and process cues that are most useful for predicting the behaviour of road users within the driving environment they experience on a day-to-day basis. In the UK, where most road users do indicate at junctions, it may be most efficient to rely upon these explicit signals, and caution and conservatism may be all that is necessary on those rare occasions where the other road users' intention seems ambiguous. In

contrast, in Malaysia, where turn indicators are used relatively infrequently (Abdul Manan & Várhelyi, 2015), road users must learn to interpret other cues effectively to function as a driver on the roads every day.

Some support was found for the notion that familiarity with the type of road user impacts drivers' judgments about their intentions at junctions. We focused on comparisons between judgments about cars (which are common vehicles in both countries) and motorcycles (which are common in Malaysia but rare in the UK). At least on invalid trials where explicit signals were of no value, Malaysian drivers appeared to be relatively adept at judging intentions of motorcyclists whereas British drivers particularly struggled in this condition. This difference might be consistent with drivers' expectations and strategies being somewhat modulated by the type of road user: Malaysian drivers perhaps have learned which implicit cues are useful for judging intentions of motorcyclists, whereas British drivers may have had insufficient exposure to learn these cues.

Before we discuss the wider practical implications of these findings, we note a few limitations to the research. First, the study recruited relatively novice drivers in both locations, with almost all participants having five years of driving experience or less. Although experience did not correlate with performance within our samples, given the low range of experience, it remains unclear whether the same pattern of results would be found with substantially more experienced drivers. One might expect that experienced drivers would be better at the task given their higher levels of expertise with driving overall. Perhaps experienced drivers from both cultures would have greater awareness of the relevant cues to predict others' intentions resulting in smaller cross-cultural differences. Alternatively, it is possible that the cross-cultural differences would be even more apparent in experienced drivers. If the effects are essentially due to exposure to a particular driving environment, experienced drivers might have even stronger expectations about which cues are relevant to judging intention than novices do. Future research should use a wider range of experience in both countries to determine the impact of experience on drivers' judgments.

Another limitation is that the task involved making judgments while passively watching videos of driving scenarios. Thus, the participants' only task was to make the required judgments. Clearly driving in the real world is far more complex, where drivers need to make moment to moment judgments while performing multiple other tasks, such as maintaining control of the vehicle, planning their own manoeuvre, and monitoring for other sources of hazard. Therefore, future research could use driving simulations to explore whether and how these cross-cultural differences in judgment manifest as differences in behaviour at junctions while driving.

The findings have important implications for driving while abroad. In particular, drivers who have learned to drive in environments where explicit signals are very reliably used may struggle to anticipate other road users' behaviour in countries where explicit signals are used to a lesser extent. The question arises as to whether informing drivers in such situations that the turn indicator may not be a reliable signal to the other road users' intentions would be sufficient to induce more accurate judgments (based on implicit cues). Future research could manipulate whether drivers are informed about the true signal validity, to determine if British drivers can decode the relevant implicit signals when they are aware it is necessary to do so.

The results also have implications for the design of automated vehicles (AVs), which need to be able to accurately predict other road users' intentions to drive safely and be accepted on the roads. The results illustrate that detecting explicit signals may be of limited use in some contexts, and implicit signals are likely to be more reliable as they are intrinsically linked to the manoeuvre itself. Given that the reliability of explicit signals differs across cultures, how much weighting should be given to implicit and explicit signals in different contexts needs to be considered. For example, to increase the accuracy in intention recognition, people who design AVs might want to put less weighting on turn indicators in Malaysia but more weighting on implicit cues.

In contrast, *providing* a valid signal appears to be beneficial across cultures. In a study conducted in the UK, it was demonstrated that 35 % of pedestrians entered the road when an AV provided an invalid signal that it was going to yield (external Human-Machine Interface; Kaleefathullah et al., 2020). This AV failure decreased subsequent trust and comprehension of the AV, and increased perceived risk of the situation. A future study could be conducted to investigate whether eHMI signals produced by an AV (see also Lee et al., 2022) have the same effect on Malaysian pedestrians. Designing human-like AVs might also result in positive subjective feedback (Butakov & Ioannou, 2015; Hartwich et al., 2018). Although our study was only about predicting the intention of other road users rather than directly measuring participants' driving behaviour during the interactions, UK drivers' judgments seemed to reflect a more cautious approach (they were more likely to judge a vehicle as turning). This finding raises the possibility there may be cross-cultural differences in how drivers prefer to be driven by AVs in the context of interacting with other road users.

5. Conclusions

This study demonstrated that British and Malaysian drivers differ in their judgments about the intended manoeuvre of approaching vehicles at junctions. British drivers relied heavily on explicit communication (turn signals) when making judgments whereas Malaysian drivers made more use of implicit communicative cues (such as trajectory, tilt, head movements). Malaysian drivers were also more accurate than British drivers in situations where motorcyclists made invalid signals. These differences could be interpreted as relating to natural differences between the two driving environments: Malaysian drivers have considerably more experience with motorcyclists than British drivers, and Malaysian road users make explicit signals less frequently. The findings provide a clear illustration that drivers' cognition is not universal but rather influenced by features of the driving environment, with important implications for road safety and the development of automated vehicles.

CRediT authorship contribution statement

Elizabeth Sheppard: Writing – original draft, Validation, Supervision, Project administration, Formal analysis, Conceptualization. **Yee Thung Lee:** Writing – review & editing, Visualization, Validation, Software, Methodology, Investigation. **Jennifer Lunt:** Writing – review & editing, Software, Resources. **Steve M.J. Janssen:** Writing – review & editing, Supervision, Project administration, Conceptualization. **Yee Mun Lee:** Writing – review & editing, Visualization, Supervision, Software, Resources, Project administration, Methodology, Conceptualization.

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

Data will be made available on request.

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