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Lee, YM orcid.org/0000-0003-3601-4191 and Sheppard, E (2016) The effect of motion and signalling on drivers' ability to predict intentions of other road users. Accident Analysis and Prevention, 95 (Part A). pp. 202-208. ISSN 0001-4575

https://doi.org/10.1016/j.aap.2016.07.011

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Title: The effect of motion and signalling on drivers' ability to predict intentions of other road users

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Abstract

Failure in making the correct judgment about the intention of an approaching vehicle at a junction could lead to a collision. This paper investigated the impact of dynamic information on drivers' judgments about the intentions of approaching cars and motorcycles, and whether a valid or invalid signal was provided was also manipulated. Participants were presented with videoclips of vehicles approaching a junction which terminated immediately before the vehicle made any manoeuvre, or images of the final frame of each video. They were asked to judge whether or not the vehicle would turn. Drivers were better in judging the manoeuvre of approaching vehicles in dynamic than static stimuli, for both vehicle types. Drivers were better in judging the manoeuvre of cars than motorcycles for videos, but not for photographs. Drivers were also better in judging the manoeuvre of approaching vehicles when a valid signal was provided than an invalid signal, demonstrating the importance of providing a valid signal while driving. However, drivers were still somewhat successful in their judgments in most of the conditions with an invalid signal, suggesting that drivers were able to focus on other cues to intention. Finally, given that dynamic stimuli more closely reflect the demands of real-life driving there may be a need for drivers to adopt a more cautious approach while inferring a motorcyclist's intentions.

Keywords Car, Intention, Motion, Motorcycle, Prediction, Signalling

1. Introduction

When two road users meet at a junction, each must estimate the others' intentions in order to decide what to do next. Errors in making such predictions about other road users' actions could result in an accident if the wrong decision is made as a consequence. For instance, we may be more likely to pull out if we think an approaching vehicle is turning off the main road than if we think the approaching vehicle will keep going, but an error could result in a collision. Research suggests that a large proportion of accidents taking place at junctions are due to right-of-way violations (Clark, Ward, Bartle & Truman, 2004; Sarani, Roslan & Saniran, 2011). While we are not aware of any data on how many of these are accounted for by failures to predict another road user's behaviour, it is possible that some of these accidents could be averted if road users are properly attuned to the behavioural intentions of others. The importance of being able to predict others' behaviour when making decisions is captured in Situation Awareness Theory (Endsley, 2000), which has been applied to various dynamic contexts including driving. There are three levels within the SA model. Level 1 is the ability to perceive the elements of the scene, while Level 2 involves comprehension and understanding of the scene. In driving, this requires individuals to understand the set of rules on the road, integrating the perceived items of the scene, and understanding them. Level 3, which is the most advanced aspect of situation awareness, involves projection and the anticipation of future events, for example, being able to anticipate the manoeuvre of other road users. It has been suggested that being able to predict the movements or behaviour of other road users is the major antecedent of successful decision making, although it does not necessarily guarantee good decision making about one's own behaviour (Endsley, 2000). Therefore, it is important to understand how accurate drivers are in making predictions about other road users' behavior, as well as the type of information they rely on to make such judgments.

The majority of previous research on judging the intention of other road users has focused on the judgments of car drivers about the behavior of cyclists, referred to as Bicycle Motorist Junction Interactions (BiMJIs). Drury and Pietraszewski (1979) conducted a study which asked drivers to predict a cyclist's intentions (turning left, turning right, going straight or stopping) by presenting them with a series of photographs depicting an approaching cyclist at a crossroads. It was found that drivers made incorrect judgments about 20% of the time when proper arm signals were provided by the cyclists as a way to communicate their intention, but the accuracy of drivers' judgments varied when they had to rely on other more informal cues while making judgments (such as different positions on the road, trailing a foot, looking over the shoulder).

More recently, Walker (2005) conducted a study which aimed to predict the probability of collisions by classifying drivers' judgments according to the likely consequences. Photos depicted cyclists who either did not or did turn into the side road while making one of four possible signal types (a proper arm signal, no arm signal but glance in the direction of the forthcoming turn, glance back over the shoulder or no indication at all). Participants were told at the beginning of each trial to execute a specific driving manoeuvre, and had to press a button (braking response) when they judged it to be not safe to perform the manoeuvre. Walker went on to categorise different trials to be 'good outcome' (managed to stop and prevent collision with the cyclist) and 'collision' (failed to stop a manoeuvre which would hit the cyclist). Collisions occurred on 7% of trails, and failures to stop were more likely in the proper arm-signal condition as compared to no signal or informal signal. It was also found that successful stop responses were slowest when the cyclist signalled correctly. It was suggested that the proper arm-signal might have caused participants to invoke extra cognitive processing, as it was associated with a communicative act. Therefore, this resulted in participants taking longer in decision making and in some cases failing to do so within the required time frame, resulting in collision.

These studies have demonstrated that drivers are generally able to successfully infer the intention of cyclists from photograph stimuli. However it is possible that the use of static photographs as stimuli could misrepresent drivers' decisions in the real dynamic road environment (Crundall et al., 2008). On one hand, static photographs allow plenty of time for careful inspection of relevant cues to intention which may make it easier for drivers to deduce what the other road user will do. On the other hand, there may be various aspects of motion that could be useful for determining intention, such as deceleration of road users planning to make a turn, the trajectory of road users as they approach the junction, changes in body position, and other antecedent movements.

It has been previously suggested that socio-cognitive processing plays a role in information processing which relates to other human beings, and hence that such processes are invoked when making decisions about intented maoeuvres of cyclists (Walker, 2005). This would be the case for other groups of vulnerable road users who appear as a visible figure of a human on the road, such as pedestrians, but perhaps not for a truck or a car where no human figure is visible (Walker & Brosnan, 2007). This raises the question about how people would make judgments about the intentions of other road user groups especially those where no human figure is visible. Motorcyclists are also a vulnerable group of road users and are clearly visible as a human figure. However, unlike bicycles, motorcycles are equipped with indicators like cars, and should use them to signal their intentions. If a motorcyclist is going to turn into a junction, one would also expect the motorcyclist to glance in the relevant direction and decelerate, although it is not as easy to see the eyes of a motorcyclist as a cyclist, due to the differing nature of their headgear.

The current study aimed to create stimuli depicting real manoeuvres as naturally as possible, comparing two types of approaching vehicle (motorcycles and cars). The study also sought to include dynamic as well as static stimuli for consideration. Participants were required to predict the manoeuvre of the approaching vehicles (turning into the junction or driving straight). One particular road configuration was used (see Figure 1.), which was selected as it has been identified as a particular source of accidents in real life (Stone & Broughton, 2002). In this particular interaction, the participant is located on the main road and has the priority of continuing going straight, while the approaching vehicle on the other side of the main road should stop and give way (if turning). The approaching vehicles' signalling behaviour was manipulated such that there were four kinds of trial: those where the vehicle continued straight and made no signal, those where the vehicle continued straight but made a signal, those where the vehicle signalled and turned and those where the vehicle did not signal but did turn. This enabled us to examine the effects of signal validity on drivers' judgments and evaluate the extent to which drivers rely on signals versus other, less explicit cues to make their judgments.

Three hypotheses were made: (1) Participants would be more accurate in predicting the manoeuvre of approaching vehicles for video stimuli than for photograph stimuli due to there being additional cues which could assist in the judgment. (2) There would be an interaction between stimulus type and vehicle type, whereby dynamic information would be more useful for cars than motorcycles. This is due to the car being a bigger vehicle so movements would be more obvious in the video stimuli whereas the tilt of a motorcycle while turning or other body language of the motorcyclist (i.e. head and body position) might be more obvious on static photographs. (3) Overall, drivers would be more accurate in judging other road users' manoeuvres when a valid signal is provided as compared to an invalid signal. Note that the signal was not predictive of the vehicles' actual intentions in this study.

2. Methods

2.1. Participants

In total 40 drivers were recruited (18 males and 22 females; an a priori power analysis confirmed that 32 participants would be needed for a medium effect size). Participants were all students studying for degrees at the University of Nottingham Malaysia Campus. Their average age was 21.75 years (S.D. = 3.12) ranging from 18 to 33 years and they reported an average of 3.02 years (S.D. = 2.68) of active driving experience since getting their driving license in Malaysia, ranging from 0.17 to 14 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 x 2 x 2 x 2 within-subjects design was used. There were four independent variables: type of approaching vehicle (car or motorcycle); manoeuvre of the approaching vehicle (turning into the junction or driving straight); signal validity (valid or invalid); type of stimulus (photographs or videos). The valid signal condition included trials where the approaching vehicle was turning with a signal provided, or going straight with no signal provided. The invalid signal condition included trials where the approaching vehicle was turning with no signal provided, or going straight with a signal provided. The dependent variable was the judgments about the manoeuvre of the approaching vehicles i.e. turn or driving straight. Two hundred and twenty four trials were presented across two blocks, one of which presented photograph stimuli and the other presented videos. Each 112-trial block included 16 stimuli which were repeated seven times each. These 16 stimuli included two different approaching vehicles (car or motorcycle) which were either turning into the junction or driving straight, with or without a signal, and were each recorded at two different junctions. Therefore, each of the trial types (i.e. turn with a signal, turn without a signal, straight with a signal and straight without a signal) made up of 25% of the total number of trials. All participants took part in both the video and photograph blocks, the order of which was counterbalanced.

2.3. Stimuli

Video Recording Two junctions near the University of Nottingham Malaysia campus (Semenyih and Broga) were used for video recordings. Videos of approaching vehicles were recorded from the viewpoint of a driver who was looking straight down the main road (refer to Figure 1: position A) using a Panasonic HDC-SD900 video camera. The approaching vehicles (a silver Toyota Vios and a black Honda PCX 150 motorcycle) travelled in the opposite direction along the road towards the camera position (refer to Figure 1: position B) at a constant speed (40 km/hour). The approaching vehicle either continued driving straight (Figure 1: position C) or turned into the junction (Figure 1: position D) in front of the video camera. Trials were recorded for each of these actions with and without the indicator being used. The driver and motorcyclist who were both male, 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.

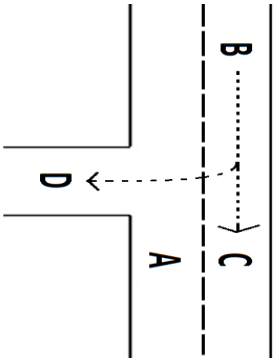

Figure 1. Initial location of approaching vehicle (B) which either travelled straight (to C) or turned into the junction (to D) and video camera (A)

Stimuli Editing Windows Live Movie Maker was used as the video editor. Each video stimulus lasted for 2000ms and for 'turn' stimuli, each video was cut off immediately prior to the point at which the wheels of the approaching vehicle started to turn. The 'no turn' stimuli were then created such that in the final frame the approaching vehicle was at the same distance from the junction as in the final frame of the corresponding 'turn' stimulus. The last scene of each video was screenshot to make the photograph stimuli in this experiment. All the stimuli were presented at a resolution of 1280 x 720 pixels (see examples in Figure 2).

Figure 2. Four examples of the progressing movement of vehicles within video stimuli (from left to right). (a) An approaching car that was travelling straight with no signal. (b) An approaching car that was turning into the junction with a signal. (c) An approaching motorcycle that was travelling straight with a signal. (d) An approaching motorcycle that was turning into the junction with no signal. Photographs on the right as the final frame of the video stimuli and were used for the static photograph stimuli condition

2.4. Procedure

Participants were seated approximately 70 cm from the computer screen with stimuli presented at a visual angle of approximately 28 x 21°. Instructions were presented on the screen which explained to participants that they were about to see a series of photographs/videos containing an approaching vehicle which was coming from the opposite direction while they were driving on the main carriageway. Participants were asked to fixate on a cross which was located in the middle of the screen for 1000ms prior to the presentation of each stimulus which lasted for 2000ms. Following offset of each stimulus, participants were presented with a prompt screen detailing the appropriate keys to press in order to correctly indicate their response. They were asked to judge whether the approaching vehicle's intention was to continue going straight (by pressing 0 on the numerical keypad) or to turn into the junction (by pressing 2 on the numerical keypad) as quickly as possible when the prompt screen was presented, although no time limit was imposed. No feedback was given to participants. All participants participated in two blocks (videos and photographs), the order of which was counterbalanced. A self-paced break was allowed between the blocks. The experiment was carried out using PsychoPy (Peirce, 2007), and all stimuli were presented in random sequence within each block.

2.5. Analyses

A signal detection analysis was used in this experiment. Data collected were categorised as 'hits', 'misses', 'false alarms' and 'correct rejections' as shown in Table 2.

Table 2. Matrix used for data categorisation

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

This approach was used for the analysis to determine drivers' accuracy in judgment in different conditions (d'), as well as whether there was any bias (c) in making certain predictions (e.g. judging 'turn' too frequently across conditions). d' (perceptual sensitivity) and c (response criterion) were calculated and analysed following MacMillan and Creelman (1991), with the log linear correction (Snodgrass & Corwin, 1988) (see Equation 1 and 2). ZHit and ZFA are the Z scores for hit rate and false alarm rate. In this context, the hit rate for a particular condition is 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 is always 14. The false alarm rate for a particular condition is equal to the number of trials on which the participant said "turn" when the vehicle in fact did not turn in that condition divided by the total number of trails on which the vehicle did not turn in that condition, which is always 14. This method of analysis effectively created a measure of participants' ability to discriminate between the two trial outcomes (turn and no turn) across conditions. Criterion c 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' more frequently, resulting values below 0, or 'straight' more frequently resulting in values above 0. Essentially it is a function of the total number of trials on which they say 'turn'.

Equation 1.

$$d' = ZHit - ZFA$$

Equation 2.

$$c = -0.5 \times (ZHit + ZFA)$$

3. Results

3.1. Perceptual Sensitivity (d')

d' was calculated to investigate how accurate drivers are in their judgments (differentiating turn and no turn trials). Eight one-sample t-tests were conducted to compare the d' of each of the conditions with 0 to investigate drivers' ability in differentiating turn and no turn trials. A score of 0 would occur if drivers could not correctly discriminate between turn and no turn trials. The significance level was adjusted using the Bonferroni method to allow for the multiple comparisons (alpha level= 0.00625). Results revealed that d' in seven out of eight conditions were significantly higher than 0, all $p < .001$ except for motorcycles providing an invalid signal presented in photographs, $p = .005$; whereas d' for cars providing an invalid signal presented in photographs was not significantly different from 0, $p = .029$. The data for all 40 participants were also subjected to a 2 x 2 x 2 repeated measures Analysis of Variance (ANOVA) comparing d' for judging an approaching vehicle's manoeuvre for the two stimuli types (photographs or videos), for different vehicle types (car or motorcycle) with a valid (turning with signal and going straight without signal) or invalid signal (turning without signal and going straight with signal) (see Figure 3).

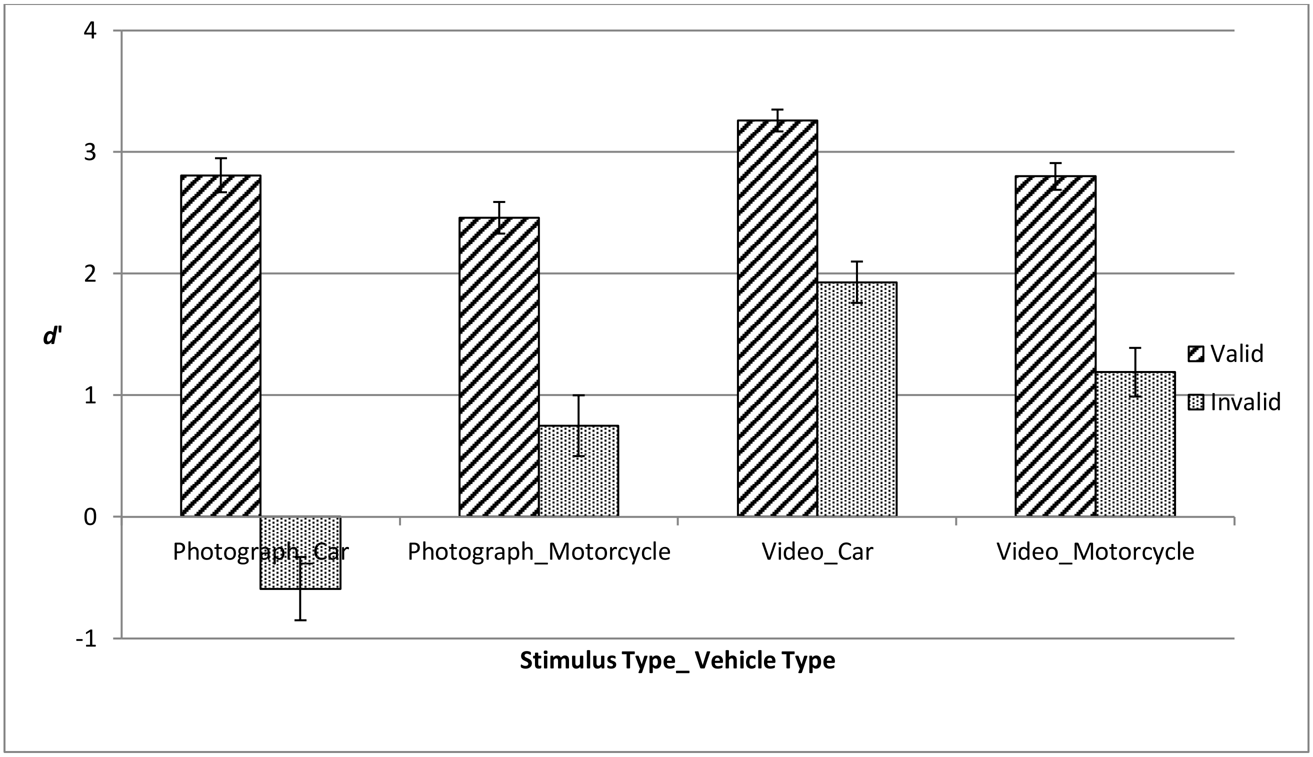

Figure 3. d' for judging an approaching vehicle's manoeuvre for the two stimulus types (photographs or videos), for cars and motorcycles with a valid or an invalid signal (error bars depict between-subjects standard error of the mean)

The ANOVA identified two main effects. First, d' for video stimuli (2.30) was significantly higher than for photograph stimuli (1.36), F(1,39) = 57.65, $p < .001$, $\eta^2_p = .600$. Second, d' was significantly higher when the vehicle in question provided a valid signal (2.83)than when it provided an invalid signal (0.82), F(1,39) = 121.18, $p < .001$, $\eta^2_p = .757$.

A two-way interaction was found between stimulus type and vehicle type, F(1,39) = 51.56, $p < .001$, $\eta^2_p = .569$. Paired-samples t-tests revealed that this interaction is due to d' for motorcycles (1.60) being higher than for cars (1.11) for photograph stimuli, t(39) = 4.01, $p < .001$, d = .634 while the d' for cars (2.59) was higher than for motorcycles (2.00) for video stimuli, t(39) = 5.31, $p < .001$, d = .840. A two-way interaction was found between stimulus type and signal validity, $F(1,39) = 15.91$, $p < .001$, $\eta^2_p = .290$. Paired-samples t-tests revealed that d’ was significantly higher when a valid signal was provided as compared to when an invalid was provided, for both photographs, $t(39) = 9.10$, $p < .001$, $d = 1.440$ (valid: 2.63 vs invalid: 0.08) and videos, $t(39) = 9.21$, $p < .001$, $d = 1.458$ (valid: 3.03 vs invalid: 1.56). Paired-samples t-tests also revealed that d’ was significantly higher for videos than photographs, when a valid signal was made, $t(39) = 3.17$, $p < .005$, $d = .502$ (videos: 3.03 vs photographs: 2.63) and when an invalid signal was made, $t(39) = 6.47$, $p < .001$, $d = 1.023$ (videos: 1.56 vs photographs: 0.08) was provided. A closer inspection revealed this interaction seems to be due to the difference between d’ for videos and d’ photographs being higher when an invalid signal was provided (1.48) than when a valid signal was provided (0.4). A two-way interaction was also found between vehicle type and signal validity, $F(1,39) = 46.04$, $p < .001$, $\eta^2_p = .541$. Paired-samples t-tests revealed that this interaction is due to d’ for cars (3.03) being higher than for motorcycles (2.63) when a valid signal was provided, $t(39) = 3.87$, $p < .001$, $d = .612$, while the d’ for motorcycles (0.97) was higher than for cars (0.67) when an invalid signal was provided, $t(39) = 2.87$, $p < .001$, $d = .454$.

These two-way interactions were subsumed by a three-way interaction, $F(1,39) = 50.28$, $p < .001$, $\eta^2_p = .563$. This interaction appears to be a result of there being a significant interaction between vehicle type and signal validity for photograph stimuli, $F(1,39) = 87.77$, $p < .001$, $\eta^2_p = .692$, but not for videos, $F(1,39) = 2.74$, $p > .05$, $\eta^2_p = .066$. For photograph stimuli, d’ was significantly higher for cars (2.81) than motorcycles (2.46) when a valid signal was provided, $t(39) = 2.45$, $p < .05$, $d = .387$, while d’ was higher for motorcycles (0.75) than for cars (-0.59) when an invalid signal was provided, $t(39) = 8.15$, $p < .005$, $d = 1.288$.

3.2. Response Criterion (c)

c is a measure of level of response bias of drivers in making judgments across conditions. A positive c indicates that drivers had a tendency to say ‘straight’ too much whereas negative c indicates that drivers had a tendency to say ‘turn’ too much. Eight one-sample t-tests were conducted to compare the c for each of the conditions with 0 to investigate whether drivers’ were biased towards judging ‘turn’ or ‘straight’. A score of 0 would occur if drivers were not biased towards judging ‘turn’ or ‘straight’ while making their judgments. The significance level was adjusted using the Bonferroni method to allow for the multiple comparisons (alpha level= 0.00625). Results revealed that c in three out of four invalid conditions were significantly lower than 0, all $p < .001$ except for motorcycles providing an invalid signal presented in videos, $p > .05$; whereas c for all valid conditions were non-significantly different from 0. Three out of four valid conditions have p value of $p > .05$ except for cars providing a valid signal presented in photographs, $p = .031$. The data for all 40 participants were subjected to a 2 x 2 x 2 repeated measures Analysis of Variance (ANOVA) comparing the response criterion (c) for judging an approaching vehicle’s manoeuvre for the different stimuli types (photographs or videos), different vehicle types (car or motorcycle) with a valid (turning with signal and going straight without signal) or invalid signal (turning without signal or going straight with signal) (see Figure 4).

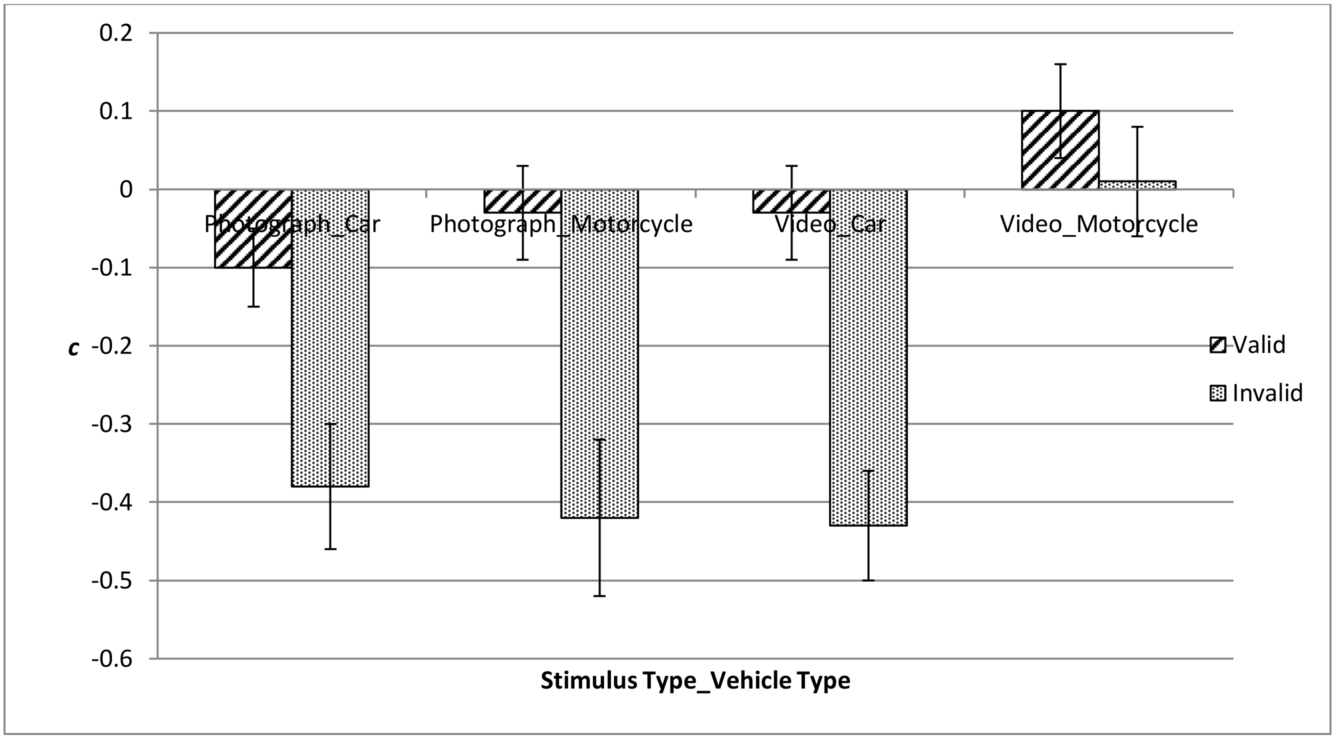

Figure 4. c for judging an approaching vehicle's manoeuvre for the two stimuli types (photographs or videos), different vehicle types (car or motorcycle) with valid or invalid signal (error bars depict between-subjects standard error of the mean)

The ANOVA identified three main effects. First, c for videos (-0.09) was significantly higher than for photographs (-0.23; drivers were more likely to judge 'turn' for photographs than videos), $F(1,39) = 7.03$, $p < .05$, $\eta^2_p = .153$. Second, c for approaching motorcycles (-0.09) was significantly higher than for cars (-0.24; drivers were more likely to judge 'turn' for cars than motorcycles), $F(1,39) = 13.15$, $p = .001$, $\eta^2_p = .252$. Third, c was significantly higher when a valid signal was provided (-0.02) than when an invalid signal was provided (-0.31; drivers were more likely to judge 'turn' when an invalid signal was provided than a valid signal), $F(1,39) = 38.83$, $p < .001$, $\eta^2_p = .499$.

A two-way interaction was found between stimulus type and vehicle type, $F(1,39) = 15.15$, $p < .001$, $\eta^2_p = .280$. Paired-samples t-tests revealed that c was significantly higher for approaching motorcycles (0.06) than cars (-0.23) for videos (drivers were more likely to ‘turn’ for cars than motorcycles for videos), $t(39) = 5.68$, $p < .001$, $d = .898$, but not for photographs, $t(39) = 0.29$, $p > .05$, $d = .046$. c was also significantly higher for videos (0.06) than photographs for motorcycles (-0.22; drivers were more likely to judge ‘turn’ for photographs than videos for motorcycles), $t(39) = 4.32$, $p < .001$, $d = .684$, but not for cars, $t(39) = 0.13$, $p > .05$, $d = .020$.

A three-way interaction between stimulus type, vehicle type and signal validity was found, $F(1,39) = 7.58$, $p < .01$, $\eta^2_p = .163$. This interaction appears to be due to there being a two-way interaction between vehicle type and signal validity for videos, $F(1,39) =25.26$, $p < .001$, $\eta^2_p = .221$ but not for photographs, $F(1,39) = 0.09$, $p > .05$, $\eta^2_p = .023$. For the video stimuli, c was significantly higher when a valid signal was provided (-0.03) than an invalid signal (-0.43) for cars, $t(39) = 5.75$, $p < .001$, $d = .907$, but no difference was found for motorcycles, $t(39) = 1.47$, $p > .05$, $d = .233$.

4. Discussion

Consistent with findings of previous researchers (Drury & Pietraszewski, 1979; Walker, 2005), this study demonstrated that in almost all conditions, drivers were able to systematically discriminate between situations where another road user intended to make a turn and situations where the intention was to continue straight on. This is evident in the fact that across most conditions, d' was positive and significantly different from 0. However, d' for photographs of approaching cars making an invalid signal were significantly below 0, suggesting that in this particular condition, drivers are actually misled and incorrectly identify turning and non-turning trials. As previous studies have focused exclusively on the ability to judge cyclists' intentions, the current research extends the field to show that drivers have the ability to judge intentions for both motorcyclists and other cars.

As expected, drivers were more accurate in their judgments (i.e. they were better at discriminating turn from no turn trials) for video than photograph stimuli and this appears to be true for both vehicle types. Therefore, the first hypothesis was supported. It seems that the approach to the manoeuvre of the vehicle as shown in video stimuli provides additional information (e.g. deceleration of the vehicles while approaching the junction before turning, the progression of the vehicles' location while getting closer to the junction, the movements of head turn for motorcyclists) compared with the static photographs where only the last scene was shown.

The second hypothesis that drivers would be more accurate in making judgments about the intention of approaching cars than approaching motorcycles for videos was also supported. This may be because the movement of the cars may be more obvious than of the motorcycles in the video stimuli. Previous research has shown that motorcycles are harder to perceive as compared to cars due to their smaller size (e.g. Crundall et al., 2008; Gershon et al., 2012; Lee et al., 2015,) For photographs, drivers were better in making judgments about the intention of other car drivers than motorcyclists when a valid signal was made, but the reverse was true when an invalid signal was made. This was also the only condition where drivers were systematically wrong in making judgments, perhaps suggesting that there are no other cues that drivers can depend on when judging the intention of other car drivers from photographs, resulting in their being misled by the signal. An approaching car does not tilt but only slightly changes its orientation in relation to the junction depending on whether it will turn or not. On the other hand, the approaching motorcycle slightly faces towards the junction when turning but the vehicle itself also tilts and the rider may also orient his head towards the direction of motion. Hence drivers have a much wider variety of relevant cues on which to base their judgments for motorcycles, resulting in less reliance on an invalid signal. Nevertheless, as the dynamic stimuli more closely reflect our experience when actually driving, the poorer performance of drivers in judging the intention of motorcycles than cars in this condition may better capture how these processes operate in daily life. If this is the case then it could perhaps contribute to the higher tendency of drivers to collide with motorcycles than cars at junctions observed both in the UK and Malaysia (e.g. DETR, 2000; IRTAD, 2011).

Thirdly, it was hypothesised that generally drivers would be more accurate in judging manoeuvres when a valid signal is provided. The hypothesis was supported and this was found consistently across conditions. These findings demonstrate the importance of vehicles providing valid signals to indicate their intended manoeuvre. However, drivers were also able to systematically discriminate turning and non-turning trials even when an invalid signal was provided in most conditions, suggesting that drivers can use some of the other cues mentioned above when making judgments.

Response bias (c) revealed that drivers adopted differing criteria for judgments when a valid and invalid signal was provided. When a valid signal was provided, drivers' response was not biased towards judging 'turn' or 'straight' regardless of vehicle type and stimulus type (i.e. response criterion was not significantly different from 0). When an invalid signal was provided, drivers' responses were significantly biased towards judging 'turn' for three of the conditions (i.e. both vehicle types presented in photographs, and cars presented in videos) while no bias was found for judging motorcycles in videos.

When considering possible reasons for this bias it may be useful to consider differences in the outcome for the driver if an error in judgment is made. If a driver judges ‘turn’ when a vehicle actually considers straight, there may be a small cost in relation to the driver slowing down or perhaps even stopping. However, if a driver judges ‘straight’ when the other vehicle is actually turning then a collision could occur. Therefore, all things being equal, it is better to judge ‘turn’ incorrectly than to judge ‘straight’ incorrectly. Perhaps, then, drivers scruitinize approaching vehicles for any cues which might indicate the vehicle will turn, and it is possible that identifying the presence of any one of these cues is sufficient to induce the driver to state the vehicle will turn. On invalid trials, therefore, drivers may tend to respond turn when they either see a turn signal being made or when they detect other cues, such as slowing down, a change in head movement, vehicle tilt and so on. Overall, this would result in a bias towards saying ‘turn’ across trials for invalid trials.

Finally, it is worth stressing that in this experiment the signal was not actually predictive of the vehicle’s movement. The experiment was designed this way in order to have equivalent numbers of valid and invalid trials. However, these proportions may not reflect the frequency with which we encounter validly and invalidly signalled manoeuvres in everyday life. For example, it seems rather unlikely that an approaching vehicle would provide a turn indication but continue to travel straight, and this is almost certainly less likely to happen than any of the other eventualities: a driver travelling straight without a signal, turning into the junction with the signal, or turning into the junction without a signal. Having said that, in Malaysia, where the study was conducted, it has been reported that motorcycles are poor in utilizing the turning indicator in some contexts (Abdul Manan & Várhelyi, 2015) so invalidly signalled manoeuvres may be relatively common. Future research could manipulate the proportion of trials on which a valid signal is made to match the conditions observed on the road to predict the errors drivers' make in daily driving.

4.1. Conclusion and Implications

This paper investigated drivers' ability to predict the manoeuvre of approaching cars and motorcycles by comparing information provided in photographs and videos. The first hypothesis was supported whereby drivers were more accurate in predicting the manoeuvre of approaching vehicles for video stimuli than photograph stimuli. The second hypothesis was also supported, whereby drivers were more accurate in judging the intention of cars for video stimuli while results for photograph stimuli varied according to the validity of the signal. The third hypothesis was also supported whereby generally drivers were more accurate in judging other vehicles' manoeuvres when a valid signal was provided.

It is worth noting that as participants in this study are young drivers with a little driving experience, the findings might not be generalisable to middle aged or older drivers with more experience. While the results here demonstrate considerable competence in making these kinds of judgment even amongst young, relatively new drivers, one might expect this competence to be further enhanced through experience, and in particular one might expect more experienced drivers to use the more reliable cues to make their judgments. Future studies could investigate the effects of experience on drivers' ability to predict the intentions of other road users.

Another limitation of the current study is that only one type of road configuration was used for investigation. In real life, there are many different ways that vehicles can interact at junctions (cf. Walker, 2005). In contrast to the set-up used by Walker (2005), in the configuration presented here the driver has right-of-way and if the other road user turns, this would be a violation. It is possible that different processes may be invoked in other situations where the driver does not have right of way and must judge other road users' intentions. Nevertheless, the ability of drivers to monitor other road users' behaviour effectively and detect the intention to make a right-of-way violation is an important part of safe driving. This is particularly important given that this study was conducted in Malaysia, as it was previously found that Malaysian drivers are more likely to judge it was safe to pull out in front of approaching vehicles at junctions than UK drivers, suggesting the possibility of greater willingness to engage in risk taking behaviour (Lee et al., 2015).

The ability to judge accurately others' intentions could increase the efficiency of traffic flow and help prevent collisions to enhance the safety of road users. The current research suggests that for dynamic stimuli, which more closely reflect the demands of real-life driving, it is harder to judge the intentions of motorcyclists than cars. This suggests that drivers should therefore adopt a more cautious approach when a motorcycle is present. Finally, in terms of application, the recent invention of autonomous vehicles (driver-less cars) has led some researchers to speculate whether such vehicles are capable of meeting the social demands of driving. For instance, it was reported that self-driving cars lack social skills, such as the ability to interpret gaze as a signal of intention (Sleek, Michel & Mikulak, 2016). Given the socio-cognitive interaction between road users is such a complex task, more research should be conducted to identify the cues that drivers use to make judgments about other road users, how and how well drivers predict what other road users intend to do, and how drivers use such predictions to guide their own behaviour. It is important for researchers to answer these questions in order to teach autonomous vehicles what to do when interacting with others.

Acknowledgements

This research was supported by funding from Fundamental Research Grant Scheme (FRGS) by Ministry of Higher Education, Malaysia (MOHE). The authors want to thank those who took part in this research.

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