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Mixed Signals: Stimulus-Response Compatibility and Car Indicator Light Configuration

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SUMMARY

The amber indicator lights on cars are designed to enable road users to efficiently predict the driver's next manoeuvre. Among other factors (e.g. luminance), the spatial configuration of these lights facilitates their interpretation (e.g. the right indicator flashes for right turns). However, several modern models of car confound this relationship by placing indicators medially relative to the headlights. Hence, the left indicator is placed to the right of the left headlight, for example. In two computer-based experiments, the object-based incompatibility that arises from this latter configuration resulted in slower, more erroneous responses to the indicated direction than for the standard configuration. These data act as a reminder to car designers that indicators, which are inherently a safety feature, should be designed with how fluently they can be processed by the human visual system in mind and not just for aesthetic appeal. Copyright © 2007 John Wiley & Sons, Ltd.

A major goal of the human visuomotor system is to fluently interpret visual stimuli and to generate the appropriate response. This is rarely more important than for a pedestrian or driver on the road, where fast and accurate interpretation of other road users' intentions are vital to avoid injury or death in an environment in which the visual system did not evolve. The amber indicator lights on the left and right sides of cars are a feature of all road vehicles, and are used by drivers to signal to other road users in which direction their next manoeuvre will be. These are bright, flashing lights and their being in working order is a legal requirement. Clearly, these important signals should be designed in sympathy with the way that the visual system works so as to enable other road users to fluently generate the appropriate response (e.g. a driver may decide to brake at a roundabout, or a pedestrian to speed up or stop walking across the street). Anything that delays the interpretation of such signals, or allows an incorrect interpretation of these signals could be potentially dangerous.

One crucial aspect of indicators is that their spatial positioning is compatible with the meaning they convey. That is a left-sided indicator signals that the car will turn left (note that this means 'left' from the perspective of the observer looking at the front of a car, not the signalling driver). Not only is it compatible in this spatial frame of reference, but the standard configuration of indicator lights are also compatible with the direction they signal in an object-based frame of reference. This is because most indicators appear in the clear

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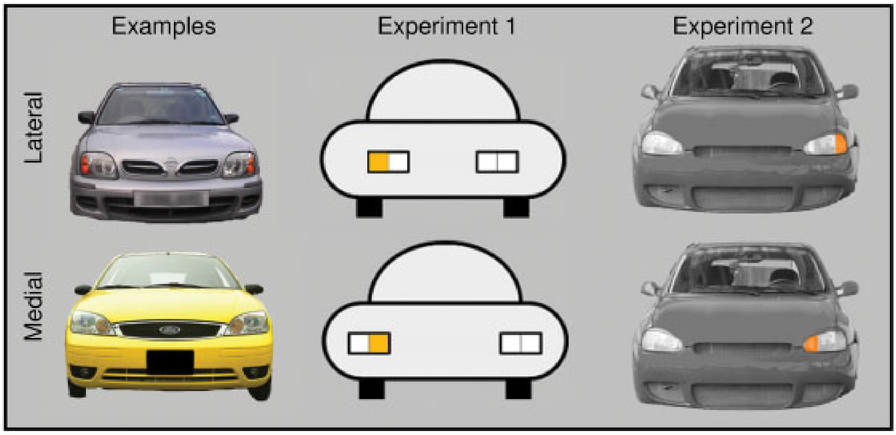

Figure 1. The two cars on the left are examples of cars that have their indicators positioned laterally with respect to the headlight (top car), and medially (lower car). Many cars do not feature this amber colouring at the location of the indicator when not functioning, and such cars were used in Experiment 2. The middle column shows examples of the stimuli used in Experiment 1 (schematic cars). The schematic car in the top middle of this figure has the headlights further apart than the lower middle illustration. Hence, the indicators appear in the same position on the screen, but appear in a different position relative to the headlight. The column on the right shows examples of stimuli used in Experiment 2 (photographs). The top cars illustrate the lateral presentation of indicator lights and the lower examples show a medial positioning of indicator lights. A colour version of this figure is available by contacting the author

section containing the headlight. Hence, the right indicator is usually placed to the right of the right headlight and the left indicator is placed to the left of the left headlight (i.e. nearer the outside of the car, see Figure 1, upper left car).

However, several modern models of car have indicators positioned nearer the centre of the car, relative to the headlight. These indicators are still spatially compatible as they appear on the correct side of the car, but relative to the headlight object, their position is incompatible with the indicated direction. For example the left indicator could appear to the right of the left headlight (e.g. see Figure 1, lower left car).

Previous studies into stimulus-response compatibility strongly suggest that this configuration will generate opposing response codes to both the stimulated side and to the position of the indicator relative to the headlight (Lamberts, Tavernier, & d'Ydewalle, 1992; Umilta & Liotti, 1987; see also Ansorge, 2003; Hommel & Lippa, 1995, for related phenomena). This may result in interference and hence impair performance when participants are asked to speedily interpret the direction in which a car will turn. Two computer-based tasks described below demonstrate that this is indeed the case. This suggests that such a configuration is inappropriate for indicators placed on vehicles and ultimately may reduce safety.

EXPERIMENT 1

This experiment used simple, schematic representations of the front of a car upon which an amber indicator could appear. Participants were required to speedily determine the direction in which the car intended to turn. It was predicted that when the indicator was

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positioned nearer the middle of the car (i.e. medially) relative to the headlight, performance would be worse (slower reaction times and perhaps more errors) than when the indicator appeared further away from the centre (i.e. laterally) relative to the headlight.

Method

Participants

The 15 participants were recruited from the School of Psychology at the University of Wales, Bangor (mean age = 20.0 years, $SD = 2.12$; three males), had normal or corrected-to-normal vision, gave informed consent and received course credit for participation.

Stimuli

The schematic cars used for Experiment 1 are illustrated in Figure 1, middle column. The cars subtended 10.5×6.6 degrees of visual angle and were presented in the centre of the computer screen. The two headlight objects within the car subtended 1.8×1.0 degrees. The headlight objects could appear either 2.9 or 3.8 degrees away from the centre of the screen (see Figure 1, top middle and lower middle sections, respectively). This manipulation was made so that the relative position of the indicator could vary, while keeping the spatial location constant across some conditions. The amber indicator could appear in any of the four headlight sections (left lateral, left medial, right medial or right lateral), and subtended 0.9×1.0 degrees. The fixation cross, which appeared at the start of trials was 0.8×0.8 degrees and was presented in the centre of the screen.

Design

There were three within-subjects factors. First, 'Headlights Type' determined whether the headlights appeared 2.9 or 3.8 degrees from the centre of the screen. Second, 'Direction' was whether the indicator appeared on the left or right side of the screen. Finally, the critical variable, 'Relative Position' was whether the indicator appeared on the outside (laterally) or the inside (medially) section of the headlight object. Lateral positions were compatible in spatial and object-based frames of reference, while medial positions were spatially compatible, but incompatible in an object-based frame of reference.

Procedure

Participants were asked to respond as quickly as possible with a right handed response (by pressing 'm' on the keyboard) if they saw an indicator flash on the right side of the screen, and to press 'z' if the indicator flashed on the left side of the screen. Each trial started with a fixation cross, appearing in the centre of the screen, for 500 milliseconds (see Figure 2). Then, a schematic car appeared in the centre of the screen for 1000 milliseconds. Next, one of the four possible indicator positions would turn amber, at which point the participant was required to respond. After 400 milliseconds, the indicator would disappear for 400 milliseconds. The indicator would flash on and off two more times, even if the participant responded during the first flash. This was done to provide the slowest participants time to respond, while keeping the number of exposures of the indicator constant. This was important in order to eliminate any spurious sequential effects produced by the effects of orienting of attention towards the indicator, which could be different on trials where one flash was seen vs. two or three flashes. A blank screen was presented for

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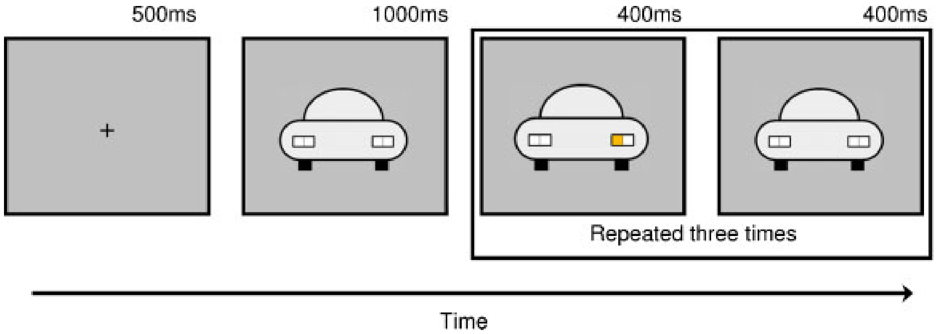

Figure 2. An example of a typical trial in Experiment 1. After seeing the car for 1 second, the indicator would blink on and off a total of three times. A colour version of this figure is available by contacting the author

1000 milliseconds between each trial. A total of 160 trials were presented (20 trials per condition) over two blocks, prior to which 10 practice trials were completed. An experimental session took approximately 15 minutes to complete.

Results and discussion

Trials on which correct responses were made contributed to median RTs for each participant in each condition and submitted to a repeated-measures ANOVA with 'Headlights Type', 'Direction' and 'Relative Position' as factors. The only effect to reach statistical significance was the main effect of 'Relative Position', since responses to indicators presented medially were slower (379 milliseconds) than to laterally presented indicators (363 milliseconds), $F(1,14) = 17.9$, $MSE = 442.0$, $p < 0.001$, (see Figure 3). No other main effect or interaction approached significance (Fs < 2.5, ps > 0.14). It was important to perform additional analyses on the trials where the indicator was positioned in retinally identical locations, but differed only in the object-based context in which it was presented. Performance was significantly worse on trials when the indicator appeared in the medial position relative to the headlight (381 milliseconds) than in the lateral relative to the

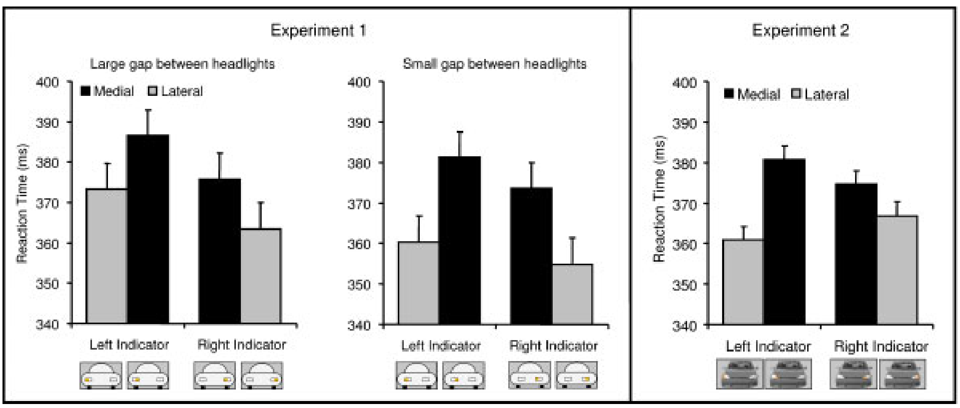

Figure 3. Graph of mean RTs for each condition in Experiments 1 and 2. Error bars represent standard errors of the means based on the procedure suggested by Loftus and Masson (1994) for within-subjects designs. A colour version of this figure is available by contacting the author

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Table 1. Mean per cent errors (standard deviations in parentheses) for each condition, for Experiments 1 and 2

	Gap between lights	Left indicator		Right indicator	
		Lateral	Medial	Lateral	Medial
Experiment 1 (schematic)	Small	1.07 (2.80)	2.14 (2.54)	0.36 (1.29)	2.14 (3.68)
	Large	0 (0)	1.43 (2.97)	0.71 (2.07)	1.78 (3.16)
Experiment 2 (photographs)	Variable	0.13 (0.52)	1.47 (2.45)	0.40 (0.83)	0.67 (1.23)

headlight (358 milliseconds), $F(1,14) = 14.8$, $MSE = 560.8$, $p = 0.002$. This is important since it demonstrates that the factor that influences response time is the object-based congruence of the indicator, not purely the spatial distance from the centre of the screen.

Errors were rarely made (1.20% of trials). Nevertheless, analysis showed that more errors were made on 'medial' trials (1.83%) than on 'lateral' trials (0.58%), $F(1,14) = 9.54$, $MSE = 4.91$, $p = 0.008$. This was also the case for lateral (0.67%) and medial (1.67%) indicators that appeared in the same spatial location, $F(1,14) = 6.0$, $MSE = 2.50$, $p = 0.028$. No other effects approached significance, mirroring the RT data (see Table 1).

Hence, the experimental hypothesis was entirely supported by the data. When the indicator appeared in a position that was compatible with response in terms of spatial and object-based frames of reference, errors were lower and responses quicker than when the object-based position relative to the headlight was incompatible with response. Responses were even affected by the object-based context of the indicator when the retinal location of the indicator was kept constant.

EXPERIMENT 2

The stimuli in Experiment 1 were highly controlled and produced reliable data that are supportive of the hypothesis that the positioning of the indicators on some models of car impairs the speedy interpretation of other road users' intentions. However, replication with more realistic stimuli is crucial in order to provide evidence that this effect may persist in the real world (Kingstone, Smilek, Ristic, Friesen, & Eastwood, 2003). This experiment used photographs of cars, upon which the amber indicators were placed. Should the effect persist under these conditions, it would provide further evidence with greater ecological validity than that of Experiment 1.

Method

Participants

Fifteen adult volunteers were recruited from the School of Psychology at the University of Wales, Bangor (mean age = 19.3 years, $SD = 1.16$; three males) had normal or corrected-to-normal vision, gave informed consent and received course credit for participation.

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Stimuli

The 10 photographs of cars were collected from the internet or taken by digital camera (see Figure 1, right column for an example). The models of car were chosen for their ambiguity as to the true position of the indicator lights when not functioning (i.e. no amber was visible). The amber indicators were then superimposed onto the greyscale photographs in each of the four positions used in Experiment 1. For each participant, five cars were randomly chosen to have their indicators appearing medially, and five cars would have their indicators presented laterally. Hence, for an individual participant, a particular car would only have medial or lateral indicators, but not both. The dimensions of these stimuli naturally varied, as they do on the road. Their width varied between 8.2 and 11.8 degrees and their height by 5.4 and 8.7 degrees. The headlights were between 1.5 and 2.2 degrees wide and 0.8 and 1.4 degrees in height. The headlights were placed between 3.2 and 4.5 degrees of visual angle away from centre.

Design and procedure

There were two within-subjects factors, 'Direction' ('left' or 'right') and 'Relative Position' ('lateral' or 'medial'). Each of the 10 cars appeared 20 times each, indicating left and right equally often, hence there were 200 trials in each session.

Results and discussion

A within-subjects ANOVA, with 'Relative Position' and 'Direction' as factors was performed. The main effect of 'Relative Position' was significant, $F(1,14) = 34.5$, $MSE = 82.3$, $p < 0.001$, again because RTs to medially positioned indicators were slower than to laterally positioned indicators (378 vs. 364 milliseconds). The main effect of 'Direction' was non-significant, $F(1,14) < 1$. There was a trend for a stronger effect of 'Relative Position' for left indicators (20 milliseconds) than right indicators (8 milliseconds), but this interaction between 'Relative Position' and 'Direction' did not reach significance, $F(1,14) = 3.30$, $MSE = 163.3$, $p = 0.091$.[1] Analysis of errors (0.67% of trials) showed that, again, significantly more errors were made on trials where the indicator was placed medially (1.06%) than laterally (0.27%), $F(1,14) = 6.59$, $MSE = 1.457$, $p = 0.022$ (see Table 1). Hence, the data accord very strongly with Experiment 1.

A final analysis concerned the relationship between average reaction time and the magnitude of the effect of medial/lateral positioning of the indicator. The overall RT and effect magnitude was calculated for the 30 participants in Experiments 1 and 2. A Pearson's correlation showed that these two variables shared a significant positive correlation, $r = 0.582$, $p < 0.001$. That is the slower the individual average RT, the stronger the negative impact a medially positioned indicator has on performance.

The results of this second experiment are clear: Even with photographs of real cars, positioning the indicator medially with respect to the headlight results in poorer performance in this task, as compared with when the indicator is placed on the outside of the car (i.e. laterally).

[1]The finding that the left indicator produces a slightly larger effect of medial positioning is interesting. First, this mirrors findings in another area of research also dealing with how one interprets directional signals produced by others (gaze perception, Ricciardelli, Ro, & Driver, 2002). Second, it suggests that the impact of the effect may be stronger in road systems where observed left-turns are more dangerous than observed right-turns.

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GENERAL DISCUSSION

This study has demonstrated that the positioning of indicators with respect to the headlights of cars can have a significant impact on how easily people can interpret the signal. The standard position of indicators is to place the right indicator to the right of the right headlight and the left indicator to the left of the left headlight. This is a theoretically sensible position to place a signal that needs to be quickly and correctly identified in the high-risk and highly demanding environment of the road. However, several modern cars position the right indicator to the left of the right headlight and the left indicator to the right of the left headlight (see Figure 1, lower cars). This study shows that this is not an appropriate position for such an important signal to be placed, as performance on trials where the indicator appeared in such a position was significantly worse than when the indicator appeared in the 'standard' position.

The additional finding that participants with slower average reaction times show a stronger effect of object-based stimulus-response incompatibility has interesting implications. The participants were a random sample of young undergraduates, who are expected to have reasonably fast reaction times. It is possible that other groups, such as older participants could be even more aversely affected by the medially positioning of indicators. Further, driving and pedestrian conditions are more demanding than the quiet experimental conditions under which the participants in this study worked. Distractions such as holding a conversation could impair indicator detection fluency and in turn exacerbate the effect observed here. Another situation where this effect could be exacerbated is when the headlights are on at night, since the now much brighter 'headlight object' would be more clearly defined as a separate perceptual unit.

In conclusion, one goal of modern car design is to produce aesthetically pleasing exteriors. However, this goal must always be achieved in sympathy with the human visual system. At high speeds and high risk, the visual system of drivers and pedestrians alike need all the help they can get in order to successfully and efficiently interpret the likely turning direction of cars, since a failure to do so could have serious and dangerous consequences. The data presented here demonstrate one example of car design that fails to consider fundamental properties of the human visual-motor system, and hence could contribute to increased accident rates.

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