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Short Communication

The effect of traffic light spacing and signal congruency on drivers' responses at urban intersections

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ABSTRACT

Traffic lights are critical in regulating traffic flow and modulate the level of service and road user safety. As suggested by studies conducted with pedestrians, traffic light spacing and signal congruency could also impact a driver's decision-making process. However, requirements related to designing signalized intersections do not always consider the spacing between two consecutive traffic lights or the congruency of the information displayed. Here, using a classic traffic psychology paradigm, we developed a hybrid Go/No-go Flanker PC-based task to explore how traffic light spacing and signal congruency modulate drivers' decisions in urban intersections. Real images of road intersections were edited to reproduce two specific conditions between traffic lights. Specifically, we manipulated both *spacing* (short vs. long) and *congruency* (congruent [e.g., red-red/green-green steady light] vs. incongruent [e.g., red-green/green-red steady light]). We found that incongruent information, displayed on short spacing traffic signals, delayed drivers' responses without being detrimental to their decision-making processes. The results of this exploratory study could offer guidance to transportation engineers to simplify traffic light information readability and increase drivers' awareness of traffic conditions and road safety.

1. Introduction

The study of attentional processes and people's ability to suppress irrelevant information is essential for understanding drivers' decision-making and performance (e.g., [1, 2]). In traffic psychology, these processes have often been studied using Go/No-go and Flanker tasks (for a recent review, see [3]). In the present study, we designed a hybrid Go/No-go Flanker PC-based task to investigate the effects of incongruent signals, spaced at different intervals, on drivers' decisions when approaching an intersection controlled by traffic lights.

Both Go/No-go and Flanker tasks are used to study the efficiency with which an individual can ignore distracting irrelevant information while processing a target (for a recent review, see [4]). A Go/No-go task requires a participant to perform an action (*e.g.*, press a button – Go) given certain stimuli, and inhibit that action (*e.g.*, not press that same button – No-go) in the presence of a different set of stimuli (for a review, see [5]). Thus, participants must respond to the majority of stimuli, the Go trials, and then suddenly withhold a response when a No-go trial is presented (*e.g.*, [6]). A Flanker task requires a participant to respond based on a specific feature of the target stimulus (*e.g.*, the direction of an arrow [→]: leftwards or rightwards) when "flanked" by irrelevant stimuli (congruent: →→[→]→→; or incongruent: ←←[→]←←). People tend to respond faster and more accurately when the target and the flankers match (*e.g.*, see [7]). That is, irrelevant stimuli (*i.e.*, flankers) would facilitate a participant's response only when they are congruent with the response. The observed outcomes of both tasks, both errors and delayed responses, are assumed to be a result of either interference or facilitation effects on decision-making processes [4].

Traffic lights represent a naturalistic example of a classic Go/No-go task. That is, a specific lighting color indicates whether a driver should stop the vehicle or continue/start driving [6]. Furthermore, Flanker-type interference has been observed under specific traffic light positioning. For example, pedestrians are more likely to cross against a red light when exposed to irrelevant traffic lights that are in their field of

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view [6]. That is, the presence of a visible green light (*i.e.*, incongruent information) on the other side of a median refuge island would encourage illegal pedestrian crossing behavior (*i.e.*, crossing against the red light). However, such an effect has not yet been studied with drivers.

If traffic light spacing impacts a driver's decision-making process, then this should be considered when designing signalized intersections with traffic lights. While international road regulations clearly allow the presence of multiple traffic signals exiting intersection areas (*e.g.*, [8, 9]), some standards do not provide consistent prescriptions about their spacing (*e.g.*, [10]). It is worth noting that one of the main requirements when designing a signalized intersection relates to the driver's response time to operate safe maneuvers (*e.g.*, stopping) [11]. However, such a requirement might not be enough in situations where it is difficult to perceive relevant information sources such as, for example, in the presence of "visual noise" [11]. An example of such a situation is when there is short spacing between traffic lights displaying incongruent information (Fig. 1).

Here, using a hybrid Go/No-go Flanker PC-based task, we explored how spacing between pairs of traffic lights and signal congruency impacted drivers' decisions in urban signalized intersections. To this end, we presented a set of 96 different traffic situations at urban intersections, where two traffic lights were always present in the scene but spacing between them and their lighting conditions varied. Participants had to decide to brake or to continue driving at these intersections according to the signal displayed by the nearest traffic light ahead of the vehicle (Fig. 1). Decisions should be independent of the second traffic light, although this could act as a distractor. We did not expect that drivers would fail to decide whether to brake or continue driving, but we hypothesized that drivers would show increased response times when facing incongruent lighting conditions between traffic lights (*e.g.*, red-green/green-red steady light) compared with congruent conditions (*e.g.*, both traffic lights being red or green). Such a delayed response should be particularly evident when the spacing between traffic lights was short.

2. Methods

2.1. Participants

The incidence of road traffic injuries and fatalities is particularly high among young adults [12]. Thus, in our study, we recruited active young adult drivers. Sixty volunteers with normal or corrected-to-normal vision (13 men; 57 right-handed; mean age [y] = 22.31; standard deviation [y] = 4.92; range [y] = 19-43) took part in the

Fig. 1. Examples of competing sources of information at intersections in Granada (Spain): Short spacing between traffic light signals (range: 12 – 26 meters) displaying incongruent steady red-green lighting.

study. All participants hold a valid driving license (having had their license for 40 months on average, range: 1-300 months). The experimental protocol was approved by the University of Granada's Institutional Review Board (IRB approval #24/CEIH/2015).

2.2. Stimuli and apparatus

Pictures of three signalized intersections were taken in Granada (Spain). The posted speed limit in the area was 50 km/h. Pictures of each intersection were taken from the driver's point of view (glasses-mounted mini camera) on the same day with similar daylight conditions.

Each of the three traffic scenarios (pictures) were modified so that the traffic lights could be: (i) steady green, (ii) steady amber, (iii) steady red, or (iv) completely off. In addition, the spacing between traffic lights were modified to create both spacing conditions (*i.e.,* short and long). The full set of stimuli for one of the three signalized intersections is presented as Supplementary Material. The spacing between the two traffic lights (measured on the screen from the middle lamp) was, on average, 6.4 degrees of visual angle (°) for the short spacing conditions, and 8° for the long spacing conditions. The average size of the light boxes closest to the driver was 2°, whereas the size of the more distant light boxes was 0.8° (short spacing condition) and 0.4° (long spacing condition). Thus, we created and presented 96 pictures (stimulus size 27.1° x 21.8°). We displayed the stimuli against a white background on a 17-in. LCD monitor, with participants seated approximately 70 cm from the screen. We used E-prime software [13] to control the presentation of the stimuli and data collection.

For the analysis, we considered only a sub-set of those stimuli (*i.e.,* 25%: 12 congruent vs. 12 incongruent trials), where a clear correct/incorrect response was measurable (*i.e.,* red-red/green-green vs. red-green/green-red steady light). That is, ambiguous situations (*e.g.,* steady amber or turned off light conditions) were only presented to minimize the occurrence of any perceptual learning effects [14].

2.3. Procedure

After providing written informed consent, participants received a general description of the experiment. First, the participants received a training block including three trials using sample pictures that were not included in the experimental stimuli. The experiment then began, consisting of two blocks of 96 trials each. That is, for the same picture, we collected two observations per participant (one per block). Each trial began with a fixation cross that remained on the screen for 500 or 1000 ms. Participants were instructed to keep their eyes on the fixation cross. The stimulus was then displayed on the screen until a response was detected (left or right-click on a mouse, with the left or right hand, as soon as they had decided whether to brake or continue driving) or 2000 ms had elapsed. Next, a black screen was displayed for another 500 ms. The sequence of trials was randomly selected for each participant and block. No feedback about the accuracy of their responses was given during the experiment (Fig. 2A). The whole experiment lasted about 15 min.

2.4. Experimental design

The experiment followed a 2 × 2 within-subjects design (Fig. 2B). The first independent variable was the *spacing* between pairs of traffic lights (two levels: short vs. long). The second independent variable was the *congruency* between lighting conditions (two levels: congruent [*i.e.,* both traffic lights presented steady green or red] vs. incongruent [*i.e.,* the first traffic light presented steady green and the second steady red and vice versa]). The dependent variable was the driver's response time.

3. Results

Response times for correct responses (94.8 % of the total responses) were submitted to a repeated-measures ANOVA with the *spacing* and *congruency* variables as the within-subject factors. This analysis revealed a significant effect of *congruency* and an interaction between *congruency* and *spacing:* $F(1,59) = 5.83$, $p = 0.019$; $F(1,59) = 4.55$, $p = 0.037$. Bonferroni-corrected post hoc comparisons of this interaction revealed that traffic lights closely spaced, when presenting incongruent information, significantly increased the driver's response time even when the decision to brake or continue driving was correct (corrected p-values < 0.05) (Fig. 3).

4. Discussion

Drivers' decisions to stop/go while crossing signalized intersections may be influenced by several factors [15], including the spacing of traffic lights. Unfortunately, most international highway codes do not consider traffic light spacing as a road safety factor (*e.g.,* [8, 9]). However, as already described in previous works involving pedestrians (*e.g.,* [6]), traffic light spacing could interfere with crossing decisions. In the

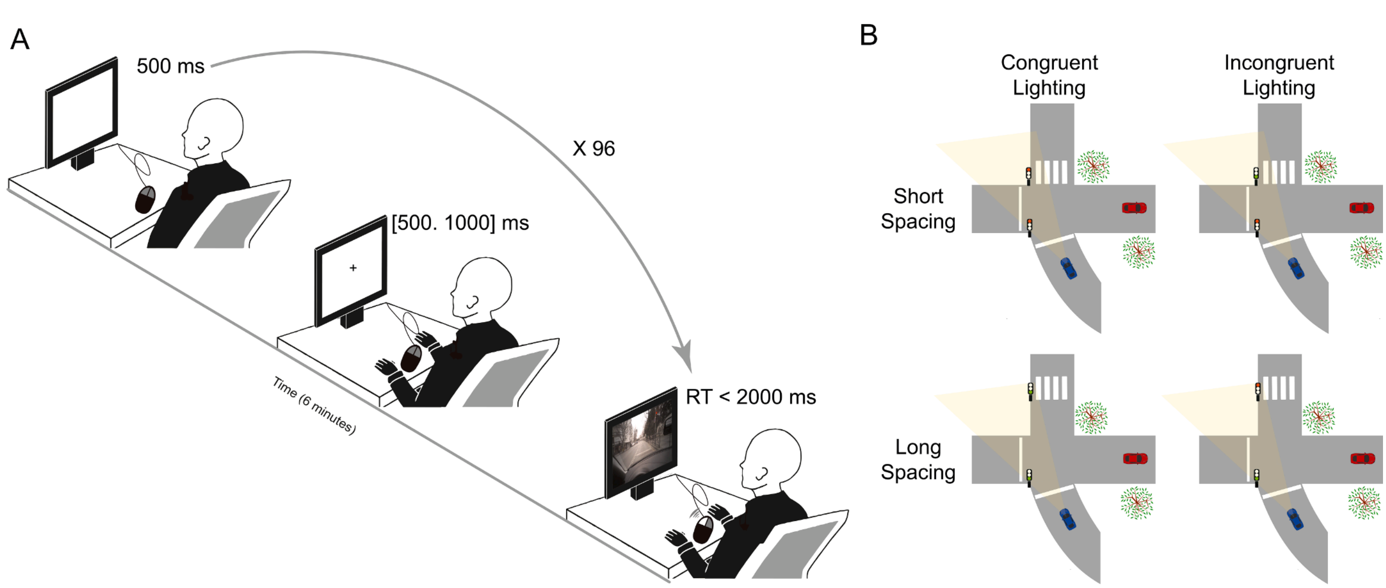

Fig. 2. (A) Schematic representation of the experimental timeline (image partially adapted from [24]). (B) Illustration of the four experimental conditions.

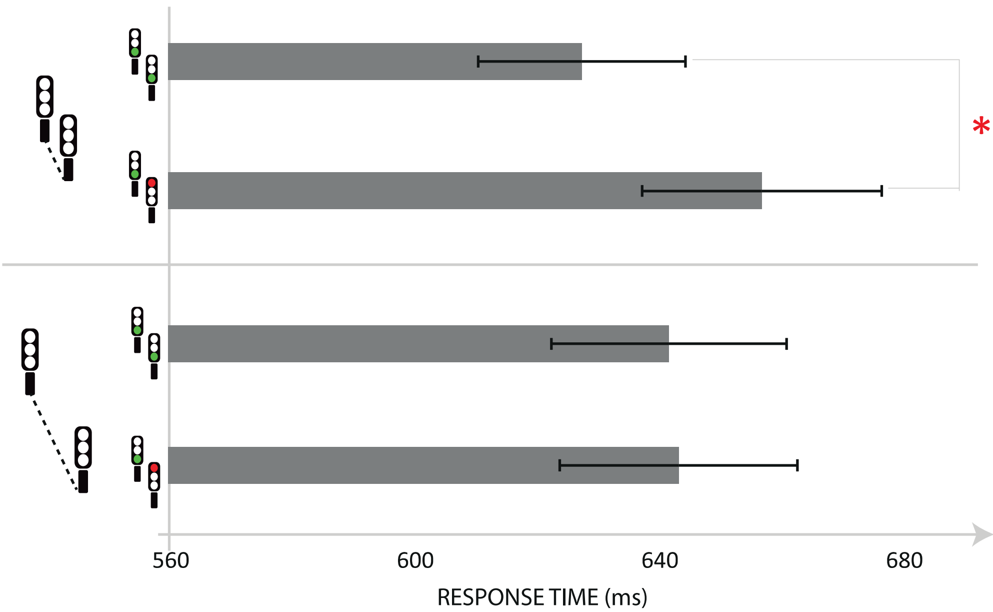

Fig. 3. Mean response times for the experimental conditions of interest. Short (upper part) and long (bottom part) spacing between traffic lights with congruent and incongruent lighting. For illustration purposes, only traffic light signals displaying congruent (steady green-green) and incongruent (steady red-green) lighting are presented. Error bars represent the SEM across subjects ($n = 60$). The asterisk represents significant differences (Bonferroni-corrected p-values < 0.05). We observed similar tendencies when including the wrong responses into the analysis.

present study, we used a hybrid Go/No-go Flanker laboratory PC-task to explore how traffic light spacing and signal congruency impacts a driver's crossing decisions in urban signalized intersections.

We found that incongruent information (*i.e.,* the combinations red-green or green-red steady lights) would directly delay drivers' responses. While in this simplified laboratory PC-based task, traffic light spacing did not impede drivers' decisions (we observed only ~5% incorrect decisions), the incongruent information increased the response time. This effect was evident for short rather than long spacing (~30 ms vs. ~2 ms) between lights. And while a delayed response of 30 ms may not seem excessive, when driving at a constant speed of 50 km/h, this delay would increase stopping distance by around 0.5 meters. Moreover, it should be considered that our results could underestimate the driver's response time in real driving. In our task, drivers attended only to the traffic light information to make their decision (*i.e.,* whether to brake or continue driving). In real driving, many other factors (*e.g.,* pavement surface condition, conflicts with surrounding vehicles, weather conditions) might influence a driver's response time, which may lead to traffic light violations (*e.g.*, red-light running, [16]) or lengthen the stopping distances [17]. These results agree with our initial hypotheses, and they are in line with previous findings from the literature concerning pedestrian traffic lights [6].

From an applied point of view, our results suggest that reducing the spacing between traffic lights of the same intersection might diminish operational benefits and increase crash rates [18]. Thus, a conservative response time – a requirement suggested by AASHTO [11] to counteract the effect of "visual noise" (here generated by pairs of traffic lights) – seems necessary. Short traffic light spacing solutions should be avoided as these would not create a safe road environment, contravening the design principles of clarity, simplicity, and readability of road intersections (*e.g.*, [19]). However, it might not be practical to reallocate the traffic light poles or create such distances along existing urban roads. In such situations, closely spaced traffic lights should avoid displaying incongruent signals. Further naturalistic and simulation studies are needed to address this problem in a more ecological way.

Overall, our results should be viewed in the context of two shortcomings related to the nationality and experience of the recruited drivers. First, it is well-documented that attitudes towards traffic safety and driving behaviors are influenced by cultural factors (e.g., [20–22]). For this study, we recruited a cohort of Spanish drivers. Thus, the generalizability of these specific findings might be somewhat limited by the reduced heterogeneity of our sample. Further research should examine the relationship between culture(country)-based differences and crossing behaviors. A second concern is that the driving experience of our participants was relatively low (3 years on average). Experience plays an important role in influencing the decision-making and safety attitudes of drivers (e.g., [23, 20]). Consequently, the effects reported here might have been influenced by driving inexperience, which suggests the need to explore how driving experience modulates crossing behaviors.

Notwithstanding the above, the results of our investigation can offer transportation engineers with useful guidance to enhance traffic light usability, increase driver awareness of the conditions about the intersection ahead, and ultimately, improve traffic safety.

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.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.treng.2022.100113.

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