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STIMULUS-RESPONSE COMPATIBILITY EFFECTS FOR WARNING SIGNALS AND STEERING RESPONSES

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Summary: Stimulus-response compatibility is relevant to the way a collision avoidance system signals a hazard. Using the location of a warning tone as the signal, standard spatial compatibility effects predict that it would be most beneficial to have the tone correspond to the desired response direction. However, because drivers typically turn away from sounds created by hazards, they may adopt a frame of reference where turning away from the warning tone is more compatible than responding toward it. This issue was examined in an experiment in which subjects responded to tones in the left or right ear by turning a steering wheel clockwise or counterclockwise, with the meaning of the tones manipulated to simulate warning signals. Two groups received typical compatibility instructions (tone instructions), and two received instructions specifying that the tone was a warning signal (warning instructions) indicating either the location of the danger (from which they were to turn away) or the escape direction (toward which they were to turn). The compatibility effect was in the same direction and of the same magnitude for both the warning instructions and the tone instructions. This outcome implies that instructions to turn away from danger did not cause subjects to adopt an avoidance frame of reference and that spatial correspondence was the overriding factor. The results suggest that collision avoidance systems should signal the escape direction, but these results need to be verified in simulated and actual driving conditions.

INTRODUCTION

In spatial stimulus-response (S-R) compatibility tasks, the mapping of spatial-location stimuli to responses is varied. The standard finding is that responses are fastest and most accurate when the stimulus locations correspond with their assigned responses (see Proctor & Reeve, 1990, for a review). For rotations of a steering wheel, the compatible mapping is a clockwise turn to a right stimulus and a counterclockwise turn to a left stimulus (Proctor, Wang, & Pick, 2003; Stins & Michaels, 1997). S-R compatibility effects are not "hard wired," but vary as a function of the intended action goal (Hommel, 1993). For example, if a stick held in the right hand operates a left response key and a stick in the left hand a right response key, and the action goal is to press the assigned key in response to a stimulus, reaction time (RT) is shorter when the left stimulus is mapped to the left key and the right stimulus to the right key than when the mapping is opposite (Riggio, Gawryszewski, & Umilta, 1986). Similarly, steering wheel responses can be coded in terms of the direction of wheel movement or the direction of hand movement (Wang, Proctor, & Pick, in press).

The results of S-R compatibility tasks may directly relate to driving a vehicle and the design of some in-vehicle systems. In particular, collision avoidance systems (CAS) are being developed to provide warnings about collision hazards, bad road conditions affecting the roadway ahead, and proximity to a vehicle in an adjacent lane. They are intended to reduce decision errors, which are a definite or probable causal factor in 52% of vehicle crashes (Dingus, Jahns, Horowitz, & Knipling, 1998). These errors are improper crash-avoidance actions, including misjudgment, false assumption, improper maneuver or driving technique, inadequate defensive driving, excessive speed, and inadequate use of lighting or signaling (Dingus et al., 1998). CAS may enable drivers to identify and locate dangerous objects in advance. Hancock and Parasuraman (1992) indicated that the warning signal not only needs to tell the operator the source of and level of danger, but also needs to indicate the correct response.

Campbell et al. (1996) investigated driver preferences for the format, location, and form of side collision alarms used in a side object-detection system, a subset of CAS, which is intended to warn of the presence of adjacent vehicles. Some of the signals were simply warning signals that did not convey directional information (e.g., an inverted triangle); others were directional and conveyed location information about a potential threat vehicle. Two kinds of location information were displayed: a descriptive signal that provided information about a driving condition (e.g., a vehicle in the blind spot, which was indicated by a visual display of an adjacent car beside the driver's car), and a prescriptive signal that provided information about how the driver should respond to the condition (e.g., a backward slash superimposed on an arrow to indicate not to turn in the direction of the arrow). Subjects preferred both descriptive and prescriptive location displays to non-directional warning signals. Consequently, although they emphasized that the study was only preliminary, Campbell et al. concluded, "The use of directional alerts that directly provide information on the location of a potential threat vehicle seems to provide some benefits in terms of conveying urgency and communicating the location of the potential changes and the nature of the situation" (p. 26). However, this study only used questionnaires and did not measure RT or any other aspect of driver performance. Because the display alerts are directional, the relationship between the stimulus and the response may result in an S-R mapping that is compatible or incompatible. Low S-R compatibility may confuse the driver and delay the reaction to a threat (Campbell et al., 1996). Thus, even though the descriptive and prescriptive location displays were both judged to be favorable, one might yield better performance than the other as a function of whether the tone location is coded as the position of the hazard that is to be avoided or the direction in which the avoidance action should occur.

Auditory displays have been suggested for warning signals because such stimuli are detected faster than visual signals (Colavita, 1974). Also, a simple tone could be easier to interpret than a text message in an emergency situation (Graham, 1999). Consequently, in the present study we examined time to respond to left and right tones. Our main concern was to evaluate whether it is better to signal the source of danger or the escape direction. We were also interested in any performance difference between subjects who had the tone described as a warning signal and those who did not.

METHOD

Subjects

Sixty-four subjects were recruited from Introductory Psychology classes at Purdue University. Sixteen subjects were assigned to each of four groups.

Apparatus and Stimuli

Subjects were seated in front of a table (height = 90 cm) on which a Porsche steering wheel (approximately 38-cm diameter) was mounted, tilted 15° from vertical away from the subject. The distance between the seat and bottom of the wheel was about 18 cm. The measurements approximate those of an ordinary automobile. The wheel could turn 8 degrees in either direction before reaching a stop and closing a switch. The switch was connected to a Micro Experimental Laboratory (MEL) serial response box (model #200A). For each trial, response direction and RT (the time from stimulus onset to switch closure) were recorded by an IBM-compatible microcomputer running the MEL program, version 2.01. A 14-inch Samtron VGA monitor connected to the computer was used as the display device for the visual signal and was placed on the table, approximately 70 cm in front of the subject.

Auditory stimuli were 2,500-Hz tones of approximately 80 dB. Each tone was presented for 100 ms, delivered monaurally to the left or the right ear through a pair of headphones. A visual ready signal (a solid white disk) appeared approximately at eye level 1 s before each tone presentation. Stimuli were delivered at the rate of 1 tone every 5 s. There were 128 trials. All possible transitions between these combinations were equally frequent, allowing for the counterbalancing of first-order sequential effects.

Procedure

With warning instructions, subjects were told that the experiment was a test for a CAS interface design, and the tones were described as warning signals. They were instructed to respond to the signal as if they were driving their own car. One group was told that the tone signaled the location of a danger source, like an adjacent car moving toward them, from which they were to turn away (the away mapping). Another group was instructed that the tone signaled the escape direction, toward which they were to turn to avoid a collision (the toward mapping). There was no restriction for hand position, but almost all subjects used both hands and put them at the sides of the steering wheel. As a comparison, data are reported for two groups of subjects from another experiment who received tone instructions (Proctor et al., 2003). These subjects were told that the test was a reaction-time task in which they were to respond to the left or right location of a tone by turning the wheel clockwise or counterclockwise: One group was instructed to turn toward the tone location and the other away from the tone location.

Design

Instructions (tone vs warning) was a between-subject variable, as was the S-R mapping (toward vs away). Rotation direction (clockwise vs counterclockwise) was a within-subject variable.

RESULTS

Reaction times less than 100 ms and greater than 1,000 ms were not included in the analysis. All subjects made less than 5% errors.

Reaction Time

There were significant main effects for instructions and S-R mapping, Fs(1, 60) = 4.16 and 17.84, MS_e = 7,251, ps = .045 and .0001. The instructions main effect indicated shorter RT for the warning instructions than for the tone instructions (Ms = 457 and 487 ms). The S-R mapping main effect was due to shorter RT for responding toward the signal than away from the signal (Ms = 440 and 504 ms). Most important, no interactions were significant (Fs < 1.95, ps > .17). With the tone instructions, RT was 456 ms for the toward mapping and 519 ms for the away mapping; with the warning instructions, the values were 425 and 488 ms for the toward and away mappings, respectively

Percentage of Error

The analysis of percentage error showed a significant S-R Mapping main effect, $F(1, 60)$ = 15.01, MS_e = 2.66, p = .0003, indicating that the error rate was less for the toward mapping (M = 0.54%) than for the away mapping (M = 1.66%), but no instructions main effect or interaction with other variables was found. A separate analysis for the warning-instruction condition showed a nearly significant S-R mapping main effect, $F(1, 30)$ = 4.02, MS_e = 4.33, p = .054. The group for which the tone location corresponded to the direction in which to turn (toward mapping) had fewer errors than the group for which the tone signaled the location of the source of the danger (away mapping) (Ms = 0.78% and 1.83%, respectively). Thus, the error data are consistent with the RT data in showing a benefit of spatial correspondence even with the warning instructions.

CONCLUSION

The present experiment was designed to investigate the possibility that signaling the source of a potential threat may produce faster avoidance reactions than signaling the direction of the proper avoidance response. The instructions to subjects were evidently successful in imparting meaning to the tones because RT was significantly shorter with the warning instructions than with the tone instructions. However, the instructions did not influence the S-R compatibility effect. Regardless of whether the stimuli were described as tones or warning signals, performance was better when the correct response was to turn toward the tone than away from the tone. Thus, turning away from the tone was not a compatible response even when the instructions described the tone as specifying the location of a danger source that was to be avoided. This outcome implies that instructions to avoid the danger did not cause subjects to adopt a frame of reference for which turning away from the signal was the most compatible response and suggests that a CAS should signal the escape direction. However, there is a major difference between the experimental situations examined in this study and driving that may mitigate this suggestion.

When driving, if a CAS signals the escape direction, the correct response is in the opposite direction of that required if the hazard is detected directly by the driver. Because of the conflict that could arise from these different S-R mappings, the relative merits of signaling escape direction versus hazard location with a CAS must be evaluated under simulated and actual driving conditions before concluding that it is best to signal escape direction.

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