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15. Abstract

This experiment was designed to compare reaction times to brake signals when they appear with red or yellow turn signals. The laboratory study simulated a daytime driving condition. The subject's task was to respond as quickly as possible to the onset of peripherally presented brake lamps (but not to turn signals), while engaged in a central tracking task. There were three lamp conditions: brake lamps alone, brake lamps while turn signal was on, and a turn-signal lamp alone. Thus, the subject's task required an immediate response in the first condition, a delayed response in the second (only after the brake lamps came on, not to the turn signal), and no response in the third condition. Turn signals were presented at two levels of luminous intensity.

The results showed that reaction times to brake signals were significantly shorter when the brake signals were presented in the context of yellow turn signals than when they were presented in the context of red turn signals. Averaged over both levels of luminous intensity and conditions with and without turn signals, the difference between yellow and red was 110 ms. The colors of turn signals had an effect whether or not the turn signal was on, but the effect was greater when it was. Older subjects were affected more by the color of turn signals than were younger subjects.

In conclusion, yellow turn signals are beneficial in situations simulated in this experiment. However, the present findings are directly applicable only to a situation where all vehicles have yellow turn signals and tail lamps are not energized.

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# INTRODUCTION

The U.S. standard allows either yellow or red color for rear turn-signal lamps, while European and Japanese standards mandate yellow. From a human factors viewpoint, there are two main questions concerning color of rear turn signals: (1) effects on reaction to turn signals themselves, and (2) effects on reactions to brake signals.

Several studies have examined the effect of color of turn signals on reactions to turn signals themselves. Cole, Dain, and Fisher (1977) and Henderson, Sivak, Olson, and Elliott (1983) reviewed several studies showing that for both night and day viewing the intensity of a yellow signal needs to be higher than that necessary for a red signal. On the other hand, Attwood (1977) measured reaction times to red and yellow turn signals with two intensities (200 and 125 cd) with and without brake lights (125 cd) or tail lights (3 and 6 cd) in simulated glare and daylight conditions. The effects of color and intensity were not significant. Furthermore, the results indicated no significant interactions between the ambient conditions and the color/intensity of the turn signals. Post (1975) found no difference between red and yellow turn-signal systems while measuring reaction times to turn signals. But in a "hazard mode" a system with yellow turn signals yielded significantly shorter reaction times than a system with red turn signals. Intensities were 275 cd for yellow and 110 cd for red.

The second and, perhaps, more complicated question is whether a turn-signal color has some effect on the detection of brake signals. Because of the relatively high importance of the information provided by brake signals, this issue may be considered more meaningful than the previous one. Although numerous studies have dealt with vehicle rear signalling, this question has not been addressed sufficiently. First, many past studies have dealt with each type of signal separately, for example, brake lamps with no turn signals (for reviews see Cole et al., 1977; Henderson et al., 1983; Sivak, 1978; Sivak and Flannagan, 1993). Second, many studies dealing with rear lighting as a whole have involved so many parameters simultaneously that no conclusion concerning the particular comparison of red and yellow turn-signal color can safely be made (e.g., Mortimer, 1970).

A simulator study of Mortimer and Sturgis (1975) is of relevance here, because it compared (among many other aspects of rear signalling) reaction times to brake signals as a function of color of turn signals (yellow versus red). The experiment was made with and without a side task (in addition to a distance-keeping task throughout the experiment). The design included two turn-signal colors combined with four lamp conditions (turn signal, brake signal, brake signal preceded by turn signal, and turn signal preceded by brake signal). In addition, both daytime and nighttime conditions were simulated (tail lamps on or off, under different illumination levels). The intensity of the signal lamps was 130 cd and of the presence lamps

10 cd. The results showed that there was no statistically significant effect (at the 0.01 level) of turn-signal color on reaction times to brake signals, although there was a tendency for shorter reaction times when the brake signals were presented in the context of yellow turn signals. However, there were only 6 trials with turn signals during a session—probably not enough experience to produce a relevant context.

A similar (not significant) effect of color was found in a field study by Mortimer (1969). However, the rear lighting and signalling system of that study also included green tail lights.

Taylor and Ng (1981) retrospectively evaluated possible system effects of turn-signal color using insurance claims. Specifically, they analyzed proportions of rear-end accidents that involved turning. The results indicated no significant difference between red and yellow rear turn signals. However, the two color systems might have been confounded with the driver populations and/or vehicles (Henderson et al., 1983). In addition, drivers use turn signals infrequently (Luoma, 1994; Mortimer, Domas, and Moore, 1974), thereby reducing the possible effect.

Hitzemeyer, Wilde, and Ellenberger (1977) conducted a survey concerning the preference between red and yellow turn signals among American soldiers and their families who had more than two years of driving experience in Europe, but had been raised in either the U.S. or Canada. The authors concluded that yellow is the superior color for rear turn-signal lamps. This finding is in agreement with the preference results of Mortimer and Sturgis (1975) made by American subjects who, presumably, were not so familiar with yellow turn signals.

Increasingly, more researchers prefer yellow over red for turn signals (see reviews by Henderson et al., 1983; Sivak, 1978). In contrast, Projector and Cook (1972) recommended that all rear signals should be red. Their strongest argument is that color coding could result in confusion in complex traffic, both in a fully standardized situation when all vehicles have it and when there is a mix of the color-coded and the all-red systems. In addition, drivers with abnormal color vision are permitted to drive motor vehicles and, therefore, color coding is not justified. However, as pointed out by Projector and Cook (1972), color coding has always been considered only as additional information.

While the reviewed studies provide some information on possible effects of turn-signal color, no systematic comparison of effects of color and intensity of turn signal on detection of brake signal has yet been carried out. Furthermore, the study of Mortimer and Sturgis (1975) used an illumination level (430 lx) that is relatively low for bright daytime, and nighttime illumination was reported only approximately. Consequently, the present study was designed to compare reaction times to brake signals as a function of the color of turn signals (red or yellow), in a situation where the color of turn signals was known to the observers.

# METHOD

## Tasks

Subjects performed two concurrent tasks. One task was to press a button as soon as a set of three brake lamps was turned on. The lamps were turned off as soon as a response was made, so the subject received immediate feedback. In addition, red or yellow turn signals were presented alone or followed by the brake signals, but subjects were asked not to react to turn signals.

The other task was to control a compensatory tracking task designed to approximate the perceptual and motor workload of driving. The tracking task was a dynamic simulated road scene on a computer-driven monitor. The subject's task was to keep the road centered on the monitor.

## Equipment

A schematic diagram of the subject's view is shown in Figure 1. The subject sat 4 m from the monitor that displayed the tracking task. Subjects moved a computer joystick left or right with their left hand to control the driving task. They used their right index finger to press a button when the brake lamps were energized. Eye position was kept approximately constant across subjects by having them place their chins in a chin rest at a fixed position.

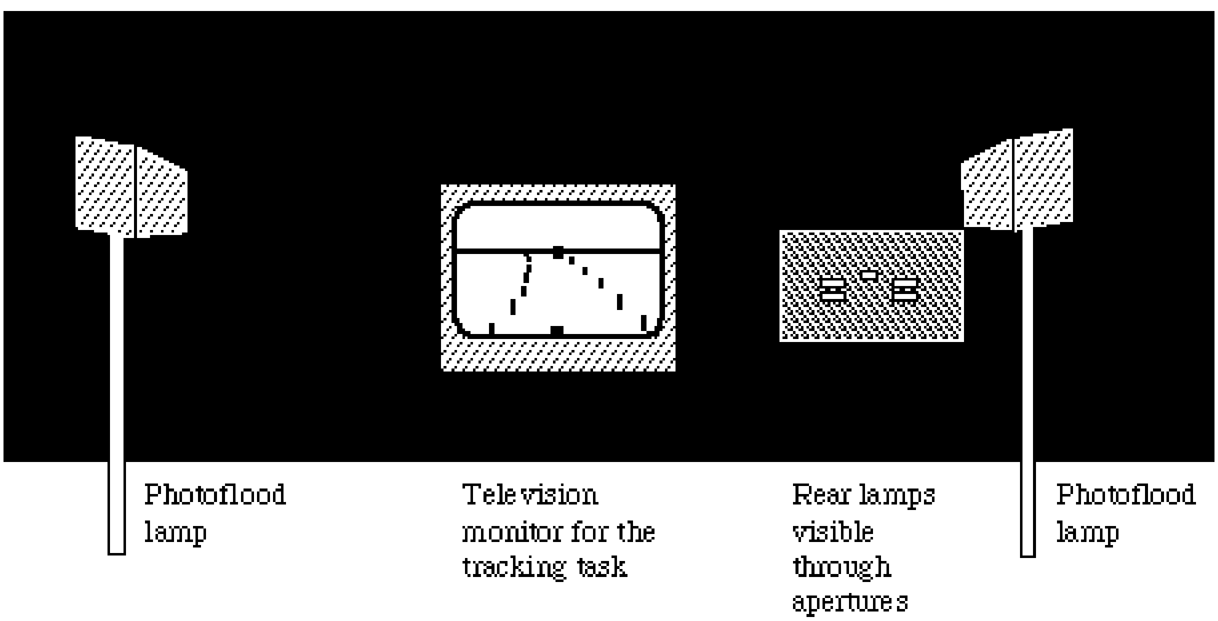


Figure 1. A schematic diagram of the subject's view.

A set of five lamps was positioned to the right side of the tracking-task monitor, such that the visual angle from the center of the set of lamps to the center of the monitor was 20°. The visual angle between the outboard lamps was 2.3°. The vertical angle between the center lamp and the lower outboard lamps was 0.5°. Lower outboard lamps were brake lamps, and turn-signal lamps were positioned above them. The distance between the lamps and subject's eye position was 4.26 m. The lamps were mounted on black stands.

Incandescent photoflood lamps and overhead fluorescent lights were used to illuminate the face of the lamp set at approximately 4,800 lx to simulate a daytime condition. A matte black cloth covered the wall that was immediately behind the tracking-task monitor and the lamp set. The resulting background luminance was measured at two locations near the lamps. On the black cloth above the lamps, the luminance was approximately 34 cd/m$^2$, while on the grey board that surrounded the lamp apertures the luminance was approximately 55 cd/m$^2$.

A timer connected to a system controlling the lamps and receiving signals from the response button was used to record the responses. Reaction times were recorded to nearest hundredth of a second. A computer was used to control the tracking task. Data from the tracking task were not stored.

**Lamps**

The study simulated a set of brake lamps and turn-signal lamps of a passenger car viewed from a distance of 30 m (see Figure 2). The dimensions and between-lamp distances were designed to represent a typical passenger car sold in the U.S.

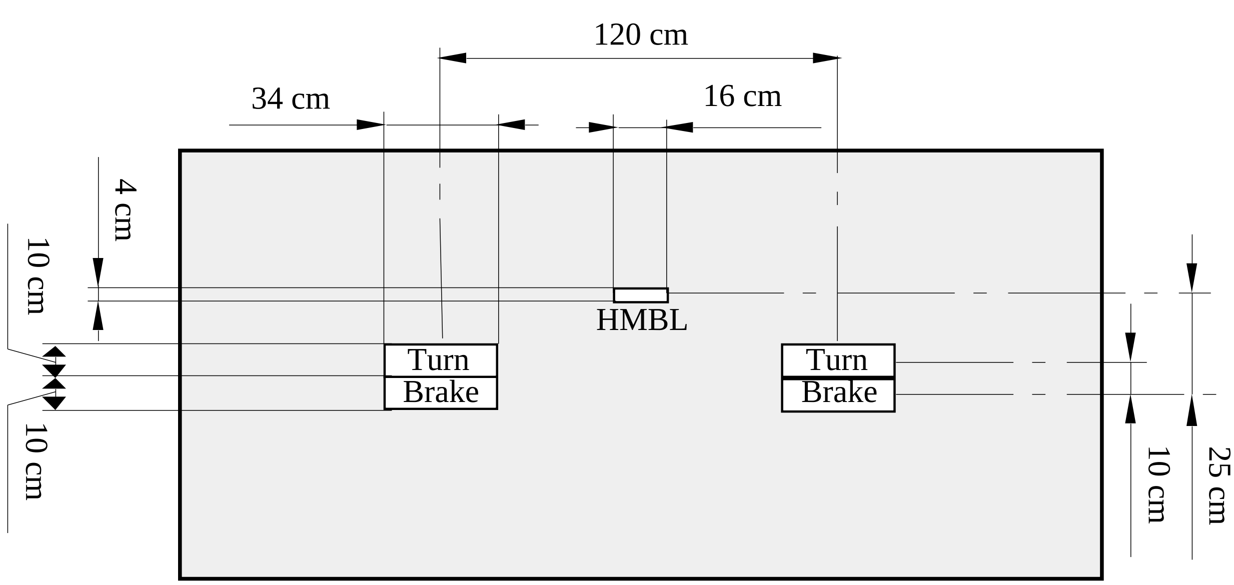


Figure 2. Simulated dimensions and between-lamp distances of the set of lamps.

To achieve the simulated geometry with the actual viewing distance of 4.26 m, a stiff grey board with a small apertures was placed in front of lamps and the dimensions and between-lamp distances were reduced correspondingly. The turn signals were presented at two levels of luminous intensity, because (a) the U.S. and European regulations for minimum luminous intensities of brake and turn signals differ considerably (see Table 1), and (b) the effects of turn-signal color were desirable to investigate with the possible effects of luminous intensity.

Table 1
Current U.S. and European standards for luminous intensities (in cd at HV) of brake lamps and turn-signal lamps (FMVSS, 1993; ECE, 1992; ECE, 1993).

| Lamp | U.S. | | Europe | |
|---|---|---|---|---|
| | Minimum | Maximum | Minimum | Maximum |
| Yellow turn-signal lamps | 130 | 750 | 50 | 350 |
| Red turn-signal lamps | 80 | 300 | - | - |
| Red outboard-brake lamps | 80 | 300 | 60 | 185 |
| Red high-mounted brake lamp | 15 | 60 | 25 | 80 |

To produce two levels of luminous intensity, turn-signal lamps of each color set were tested with and without a neural density filter in front of the aperture. The filter had a transmittance of approximately 62%. The lamp intensities directed toward the eyepoint of the observers were measured every test day using a Photo Research Pritchard 1980A photometer. The actual luminous intensities and chromaticity values for each type of lamps are given in Table 2. The flash rate of the turn signal was 90 per minute and the duty cycle was 51%. All these aspects were approximately within the current U.S. standards, except for a yellow turn signal with filter (FMVSS, 1993).

Table 2
Mean effective luminous intensity at the simulated viewing distance of 30 m, by lamp and filter, averaged over all test days; and the corresponding chromaticity coordinates of the lamps.

| Lamp | Luminous intensity (cd) | | Chromaticity coordinate | |
|---|---|---|---|---|
| | Without filter | With filter | x | y |
| Yellow turn-signal lamps | 130 | 80 | 0.57 | 0.43 |
| Red turn-signal lamps | 130 | 79 | 0.66 | 0.34 |
| Red outboard-brake lamps | 81 | | 0.66 | 0.34 |
| Red high-mounted brake lamp | 25 | | 0.66 | 0.34 |

## Subjects

Sixteen paid subjects participated in the study. Eight subjects were between the ages of 20 and 25 (with a mean of 22), and eight were between the ages of 61 and 73 (with a mean of 66). There were four females and four males in each age group. Each subject had normal red-green color vision according to a test of Ichikawa, Hukami, Tanabe, and Kawakimi (1978).

## Design

There were three rear lamp conditions:

(1) *Brake lamps*. All three red lamps were energized. This lamp condition was repeated 16 times per block.

(2) *Brake lamps while a turn signal was on.* First, one of the two turn-signal lamps began flashing and, after a delay, all three red brake lamps were energized. The delay between the onset of the turn signal and the brake signal was either 1.4 or 3.4 seconds. This lamp condition was repeated 16 times per block (8 times for each brake-signal delay).

(3) *Turn-signal lamp.* One of the two turn-signal lamps began flashing. This lamp condition was repeated 8 times per block.

One combination of the two colors of the turn-signal lamps and the two levels of luminous intensity were tested during each block of trials. The turn signal started with the off phase. The order of the four color-by-intensity combinations was balanced across subjects within each age-by-sex subject group.

## Procedure

Each subject was tested individually during a one-hour session consisting of five blocks, including one practice block of ten trials, and four test blocks of 40 trials each. In order to strengthen the context effects of turn-signal color, turn-signal color was changed only once during the session. The tracking task was explained first, and subjects were allowed to practice until they felt comfortable with it. The reaction time task was then introduced.

On each trial, one of the lamp conditions was presented. If the subject responded, the lamps were turned off immediately; otherwise, the lamps were turned off after six seconds. Reaction times longer than three seconds were not recorded; they were considered missed trials and rerun at the end of the block. The number of incorrect responses (the number of missed trials and the number of responses to turn signals without or before brake signals) was counted.

There were five lengths of intertrial intervals: 6, 8, 10, 12, and 14 seconds. These intervals, as well as delays in the second lamp condition, were randomized, so that the onset of the next lamp appeared unpredictable to the subject. Whether the right or left turn-signal lamp was energized on a given trial was also randomized (independently), as was the type of lamp condition. Short breaks were given between blocks. Before the beginning of each block, the subject was informed about the particular color that would be used for turn signals during that block.

Two experimenters carried out the study, one controlling onset of the lamps and randomizing the sequence of lamp presentations, and another recording the reaction times and errors.

## RESULTS

### Parametric analysis

An analysis of variance was performed on reaction times. The analysis incorporated three within-subject variables (color, luminous intensity, and lamp condition) and two between-subject variables (age and sex). The main effects of the following variables were statistically significant: (1) *Color*, $F(1,12) = 21.1$, $p < 0.001$, with longer reaction times in the blocks of trials with red turn signals, (2) *Lamp condition*, $F(1,12) = 6.56$, $p < 0.03$, with longer reaction times for brake lamps while turn signal was on, and (3) *Age*, $F(1,12) = 25.8$, $p < 0.001$, with longer reaction times for older subjects. The effects of luminous intensity and sex were not significant.

The effect of color by luminous intensity is shown in Figure 3. The interaction between these variables was not statistically significant.

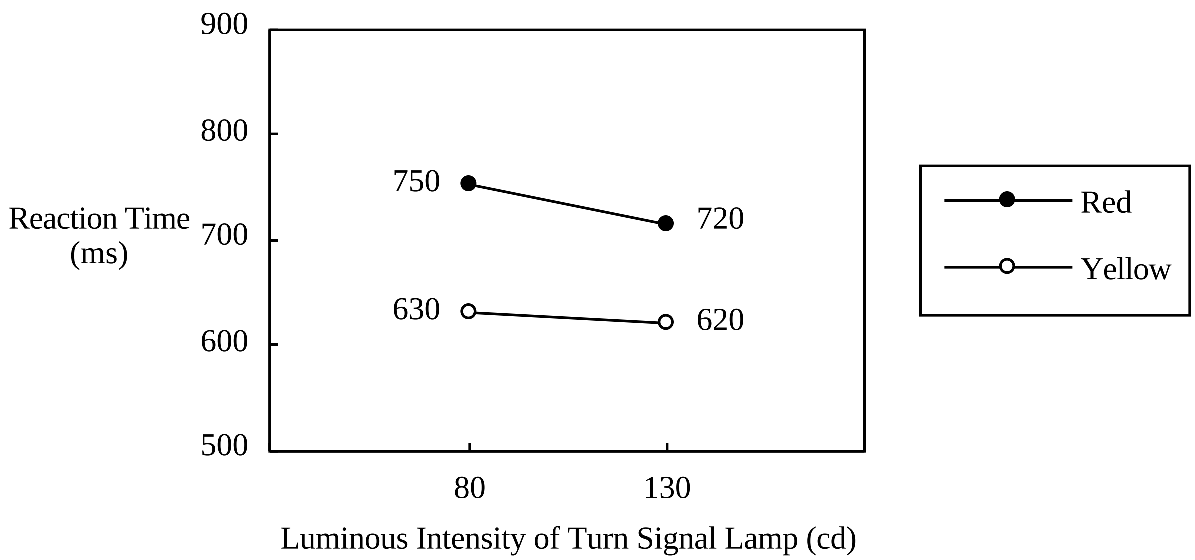


Figure 3. Mean reaction time to brake lamps by color and intensity of turn-signal lamps.

The interaction between colors and lamp condition (Figure 4) was marginally not significant ($F(1,12) = 4.74$, $p = 0.05$), but it suggests that the effect of color was greater when the turn signal was on.

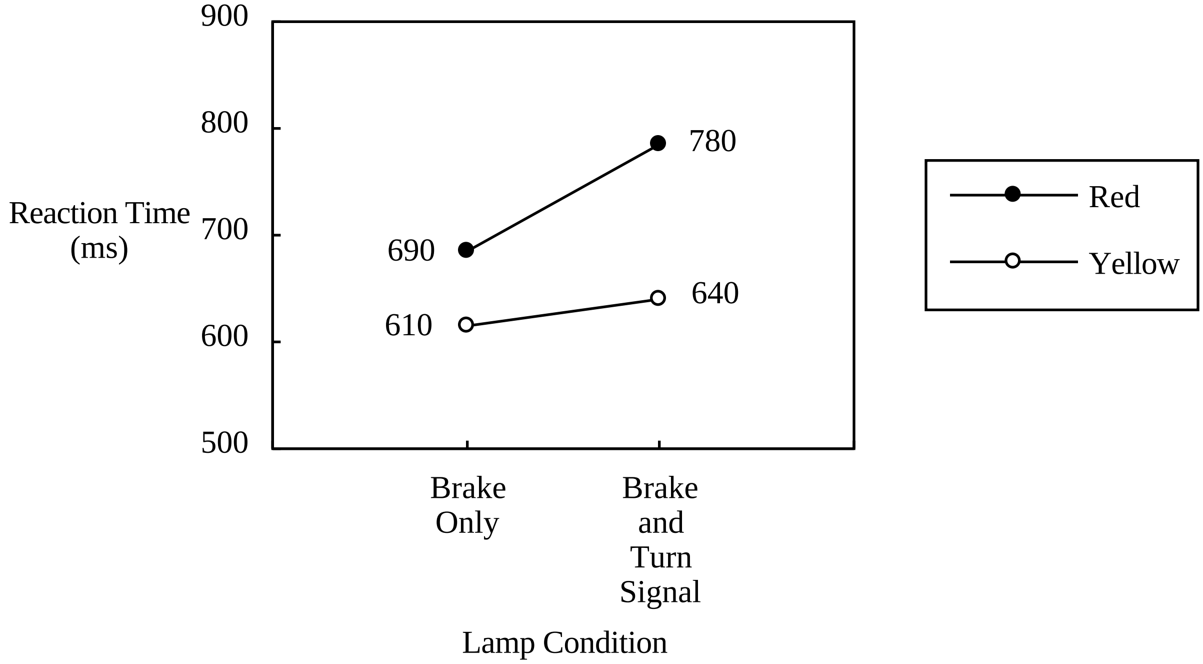


Figure 4. Mean reaction time to brake lamps by color of turn-signal lamps and lamp condition.

Figure 5 shows the effect of age by color. The significant interaction between those variables ($F(1,12) = 5.62$, $p < 0.04$) indicates that the older subjects were affected more by red turn signals than were the younger subjects. None of the other interactions were statistically significant.

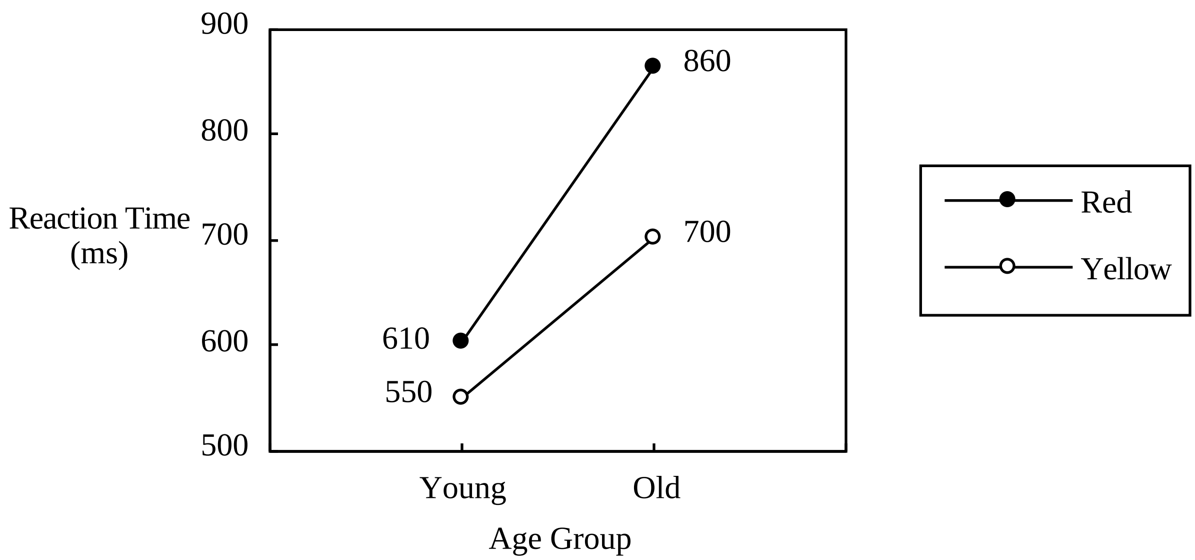


Figure 5. Mean reaction time to brake lamps by color of turn-signal lamps and age group.

### Long-latency and incorrect responses

Table 3 shows the proportions of trials on which either the reaction time was long (greater than one second) or the response was incorrect (pushing the button in response to a turn signal, or failing to push it in response to a brake signal) by color of turn signals. The proportion of trials involving reaction times longer than one second or incorrect responses was significantly higher for red than for yellow turn signals, $X^2(1) = 36.1$, $p < .0001$.

Table 3
Percentages of fast and correct responses, and slow or incorrect responses, by turn-signal color.

| Type of response | Turn-signal color | |
|---|---|---|
| | Red | Yellow |
| Fast and correct responses | 89.8 | 95.9 |
| Slow or incorrect responses | 10.2 | 4.1 |

## DISCUSSION

This study was designed to investigate the effects of turn-signal color on reaction times to brake signals. Specifically, the experiment compared reaction times to brake signals when they appeared with red or yellow turn signals, and the color of turn signals was known to subjects.

The main finding of this study is that yellow turn signals, in comparison to red turn signals, led to significantly shorter reaction times to brake signals. Averaged over both levels of luminous intensity and both lamp conditions, the difference between yellow and red was 110 ms. For the condition representing minimum luminous intensity levels of U.S. standards, the average difference was even more substantial (130 ms).

The distracting effect of red turn signals appeared whether or not the turn signal was on, but the effect was greater when it was. One could ask why the effect was also present when no turn signal was on. This effect can be explained by the relevant context. Specifically, the subjects knew whether the red or the yellow turn signals were to be expected. In the blocks involving red turn signals, subjects could distinguish the brake signals from turn signals based on the number of the lamps. (The effects of flashing, or the slightly different angular position of the outboard lamps, are presumed to be relatively minor.) On the other hand, in the blocks involving yellow turn signals, the subjects had an additional cue, namely the color.

The results showed that older subjects did not perform as well as younger subjects. This was especially the case for red turn signals—the more demanding stimuli. This finding is in agreement with many previous results concerning age-related problems in divided attention tasks involving complex or demanding conditions (see reviews by Hakamies-Blomqvist, 1994; Schieber, 1994).

In practice, a color separation is frequently accompanied by spatial separation of functions for turn and brake, because cars with yellow turn signals have a dedicated lamp for these two functions. On the other hand, cars with red turn signals are more frequently equipped with one lamp for both functions. In this experiment both the red and yellow turn signals were separated from the brake lamps. Thus, this experiment did not examine the effect of spatial separation. However, previous studies (reviewed by Henderson et al., 1983) have shown that spatial separation of functions results in shorter reaction times. Consequently, the beneficial effect of yellow turn signals would presumably be even more substantial if compared to red turn signals with no spatial separation.

In conclusion, the present data indicate that yellow turn signals are beneficial in the situations simulated in this experiment. However, there are certain limitations of this finding. First, measurement of reaction times to brake signals is only one aspect of possible effects of turn-signal color. Second, in a traffic situation with a mix of both yellow and red turn signals drivers may not know which turn-signal color a preceding vehicle has. In such a situation, the effect of yellow turn signals would likely be smaller than in the present study. In other words, the present findings are directly applicable only to a situation where all vehicles have yellow turn signals. Third, the effect may be smaller when tail lamps are energized, because red tail lamps, like red turn signals, would also prevent drivers from being able to take advantage of red color as a unique indicator of braking. However, in the case of tail lamps, unlike turn signals, the luminous intensities are substantially lower than those of brake lamps. Also, tail lamps are on steadily, while turn and brake signals both appear briefly and irregularly. That may mean that tail lamps are inherently less confusable with brake lamps, and therefore do not need to be distinguished by color. Nevertheless, future research should evaluate the benefits of yellow turn signals when both red and yellow turn-signal colors appear and tail lamps are on.

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