JESK J Ergon Soc Korea 2017; 36(5): 459-466
http://dx.doi.org/10.5143/JESK.2017.36.5.459
http://jesk.or.kr eISSN:2093-8462

Effects of Traffic Signals with a Countdown Indicator: Driver's Reaction Time and Subjective Satisfaction in Driving Simulation

Joonho Chang[1], **Kihyo Jung**[2]

[1]Pennsylvania State University, Department of Industrial and Manufacturing Engineering, State College, PA 16801
[2]School of Industrial Engineering, University of Ulsan, Ulsan, 44610

Corresponding Author
Kihyo Jung
School of Industrial Engineering,
University of Ulsan, Ulsan, 44610
Mobile : +82-10-5526-6381
Email : kjung@ulsan.ac.kr

Received : August 08, 2017
Revised : August 19, 2017
Accepted : September 04, 2017

Objective: This study examined two traffic signals with a countdown indicator in terms of driver's reaction time and subjective satisfaction score and their performance was compared with a standard traffic signal in driving simulation.

Background: Dilemma zone is created when a traffic light changes at intersections. It often pushes drivers to rush in urgent and premature decision making whether to go or stop and thus induces unnecessary mental load among drivers, which may lead to sudden conflicts with following vehicles at intersections.

Method: Forty college students (male: 20, female: 20) participated in this driving simulation study. Three traffic signals were employed: (1) standard traffic signal; (2) countdown-separated signal; and (3) countdown-overlaid signal. The countdown-separated and countdown-overlaid signals were designed to inform drivers of the remaining time of a green light before tuning to an amber light. Reaction times (sec) and satisfaction scores (7-point scale) for the two signals with a countdown indicator were compared with those for the standard traffic signal.

Results: Reaction times of the countdown-separated (0.49 sec) and countdown-overlaid (0.43 sec) signals were significantly shorter than that of the standard signal (0.67 sec). Satisfaction scores of the countdown-separated (5.3 point) and countdown-overlaid (5.6 point) signals were greater than that of the standard signal (3.8 point). Lastly, the countdown-overlaid signal showed better performance than the countdown-separated signal, but their differences in reaction time (0.06 sec) and satisfaction score (0.3 point) were small.

Conclusion: Traffic signals with a countdown indicator can improve drivers' reaction time and satisfaction score than the standard traffic signal.

Application: Traffic signals with a countdown indicator will be useful for reducing the length of dilemma zone at intersections, by allowing drivers to predict the remaining time of a green light.

Keywords: Traffic signal with a countdown indicator, Countdown-separated signal, Countdown-overlaid signal, Dilemma zone

1. Introduction

Traffic signals at signalized intersections create dilemma zone on the road, which can force drivers to determine whether to stop or go before an upcoming red signal

(Gazis et al., 1960). If a driver within the dilemma zone determines to abruptly stop his/her vehicle, this could induce a sudden conflict with following vehicles, which may lead to rear-end crashes (Polders et al., 2015; Richards et al., 2005). In addition, if the driver within the dilemma zone determines to enter a box junction late, his/her vehicle is likely to commit red light running, which may result in angular crashes (Bonneson and Son, 2003; Gazis et al., 1960; Polders et al., 2015). In fact, most traffic conflicts among road users occur when traffic signals change, because more dilemma zones appear at the moments (Yi et al., 2010; Chin and Quddus, 2003). Thus, a more informative traffic signal system that can reduce the length of dilemma zone is recommended for improving driving safety and reducing driver's mental load at signalized intersections.

A current three-color traffic signal system generally consists of red (for stop), amber (for ready to stop), and green (for proceeding) lights and it simply informs drivers of traffic signal change with alternating the light colors (Li et al., 2014; Limanond et al., 2010). However, since the current traffic signal system does not provide additional information (e.g., a total duration of each light color, remaining time until the next signal), it often pushes drivers to rush in urgent and premature decision making to stop or proceed at signalized intersections when a traffic signal changes (Long et al., 2013; Lum and Halim, 2006). This unnecessary mental load may induce more traffic conflicts at signalized intersections. Lum and Halim (2006) raised concern that uncertainty and the lack of information before an upcoming traffic light is one of the primary reasons of sudden traffic conflicts on the road.

Studies have been proposing traffic signals with forewarning indicators or signs to help drivers predict available time of traffic lights. Behrendt (1970) tested a traffic signal with a green-flashing light, informing drivers of forewarning before turning to an amber light, but failed to find its significance in the reduction of vehicle crashes. Similarly, Newton et al. (1997) examined a traffic signal with an amber-flashing light, and they concluded that the amber-flashing light could have the potential to reduce the number of red light runners, which could help decrease the length of dilemma zone. More recently, Lum and Halim (2006) developed a traffic signal with a countdown indicator that was designed to inform drivers of the remaining time (sec) of a green light. Their empirical results showed that the number of red light runners was reduced by as much as 65% at 1.5 month after its installation in Singapore, but the change of driving performance and behavior were not reported in the study.

This study investigated the performance of two traffic signals with a countdown indicator in terms of reaction time and satisfaction score, and they were compared with a standard three-color traffic signal system. The two traffic signals with a countdown indicator (called countdown-separated and countdown-overlaid signals) were designed to inform drivers of the remaining time of the onset of a green light before tuning to an amber light. A driving scenario was developed and a driving simulator was prepared to measure driver's reaction time and satisfaction score as a function of the three traffic signals.

2. Experimental Methods

2.1 Participants

Forty college students (male: 20, female: 20) participated in the simulated driving experiment. Their ages were ranged from 21 to 27 years (mean = 23.0, SD = 1.12). The participants were all licensed drivers with normal vision and had no health issues. They were informed of the objective and experimental procedure of the study and signed an informed consent form before the experiment.

2.2 Experimental design

This study employed one factor (traffic signal) within-subject design to examine the effect of three different traffic signals. The three systems were (1) standard signal; (2) countdown-separated signal; and (3) countdown-overlaid signal. The standard signal had three lights of red, amber, and green as shown in Figure 1a. The countdown-separated signal basically had the same three lights like the standard signal had, but a small auxiliary display was additionally installed on the top of a green lamp, as illustrated in Figure 1b. This auxiliary display informed the remaining seconds of the onset of a green light before turning to an amber light. Lastly, the countdown-overlaid signal also had similar functions to the countdown-separated signal but the remaining seconds of the onset of a green light were overlaid on a green light bulb, as shown in Figure 1c.

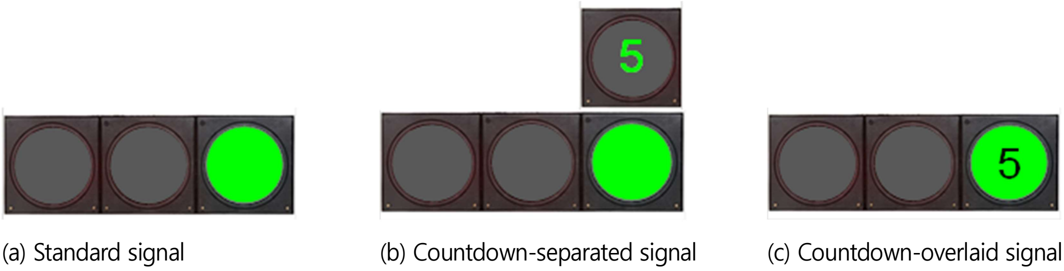

Figure 1. Three traffic signal systems in the experiment

Two dependent variables were measured in the study: (1) reaction time and (2) satisfaction score. The reaction time (unit: sec) was measured from the time when a green light turned to an amber light to the moment that a participant successfully pushed a brake pedal with the right foot. The subjective satisfaction score was measured using a 7-point (1: strongly dissatisfied, 4: neutral, 7: strongly satisfied) Likert scale by referring to existing studies (Chang and Jung, 2017; Jung and Jang, 2015).

A driving simulator (GTs Plus, PNS) was employed in this study, as shown in Figure 2. The driving simulator consisted of a steering wheel for maneuvering and two pedals for acceleration and brake. A large display was installed 5 m away from the driving simulator to display a front view (i.e., driving scene and traffic signals) that was set to appear similar to real driving environment. A driving scenario (including three signalized intersections) was developed to enable a participant to drive a vehicle at about 60km/hour without other road users, in order to control the effects of road conditions and traffics. All traffic signals were set to a green light before a subject vehicle approached, and they were programmed to randomly turn to an amber light when the vehicle arrived

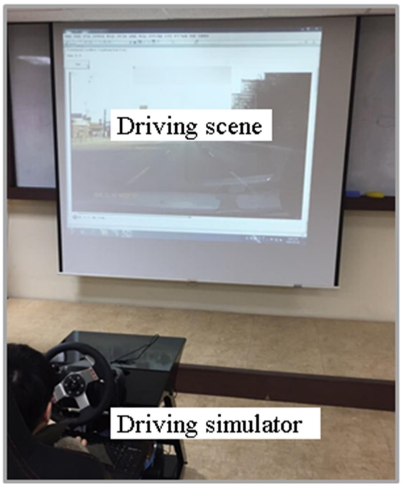

Figure 2. Experiment layout and driving simulator

at each signalized intersection in order to prevent a participant from predicting traffic signal change.

Testing was conducted in four steps: (1) introduction; (2) practice; (3) main experiment; and (4) debriefing. In the first step, the purpose of the study and the experimental procedure were explained to participants, and their informed consents were obtained. In the second step, participants were asked to do practice trials to become familiarized with the simulated driving environment. In the third step, driving simulation was conducted. The order of experiments was randomized and six repetitions were made for each traffic signal (a total number of experiments: 18 = 3 signals × 6 repetitions). The traffic signal change from a green light to an amber light appeared in only three of the six repetitions to prevent a participant from predicting the traffic signal change. In the last step, a debrief session was held to ask participant's opinions about the experimental results.

2.3 Statistical testing

One-factor within-subject analysis of variance (ANOVA) was conducted on each of the dependent variables with Minitab (v16.0, Minitab Inc.) with $\alpha = 0.05$. Tukey tests were employed as post-hoc analysis at the same significance level.

3. Results

Reaction time of the countdown-overlaid signal was significantly shorter than those of other two traffic signals, as shown in Figure 3 ($F(2, 78) = 42.76$, $p < 0.001$). The reaction time of the countdown-overlaid signal (mean ± SE; 0.43 ± 0.03 sec) was slightly shorter (0.06 sec) than that of the countdown-separated signal (0.49 ± 0.02 sec). However, it was disproportionally faster by as much as 0.24 sec than that of the standard signal (0.67 ± 0.04 sec). Tukey tests grouped the three signals into three different groups, respectively (Figure 3).

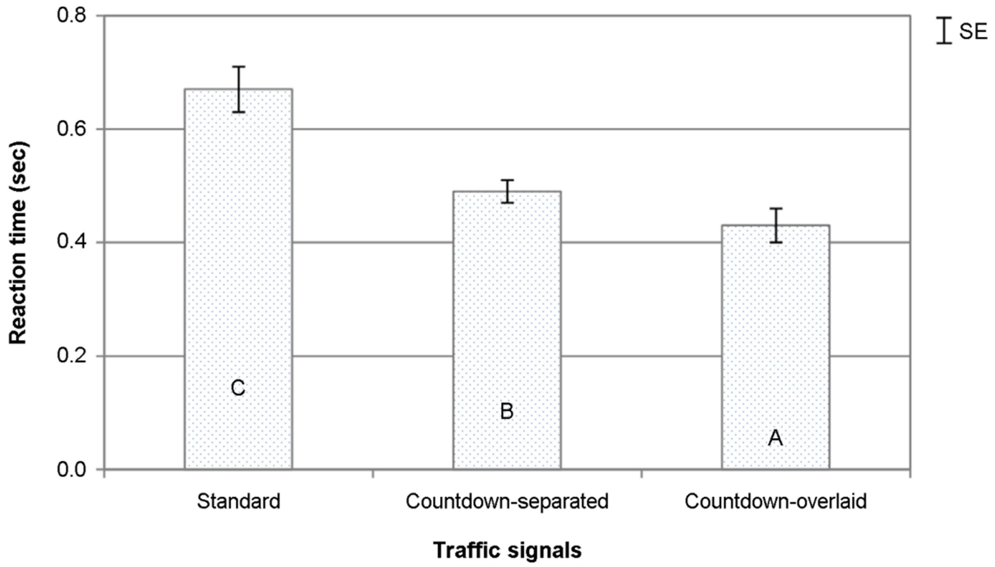

Figure 3. Reaction time of three traffic signals (Letters indicate statistically different groups by Tukey: C > B > A)

Satisfaction score of the countdown-overlaid signal was significantly greater than those of the others, as shown in Figure 4 ($F(2, 78) = 24.21$, $p < 0.001$). The satisfaction score of the countdown-overlaid signal (5.6 ± 0.23 point) was slightly greater (0.3 point) than that of the countdown-separated signal (5.3 ± 0.24 point). However, it was remarkably higher by as much as 1.8 point than that of the standard signal (3.8 ± 0.23 point). Tukey tests determined the three traffic signals into three different groups, respectively (Figure 4).

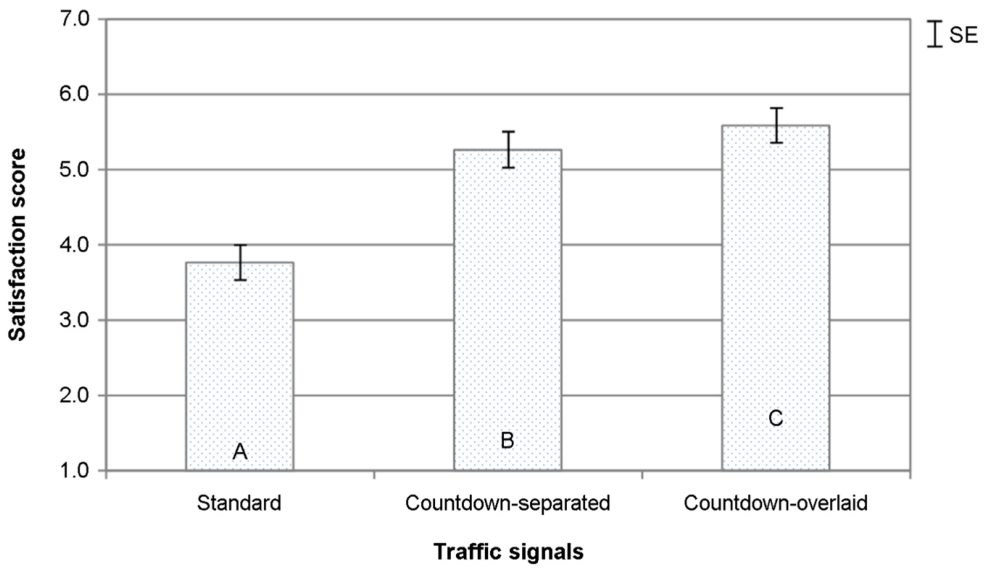

Figure 4. Satisfaction score of three traffic signals (Letters indicate statistically different groups by Tukey: C > B > A)

4. Discussion

The present study examined the performance of two traffic signals with a countdown indicator and compared them with the current three color traffic signal system (called the standard signal in the study). The two traffic signals with a countdown indicator were designed to inform drivers of the remaining time (sec) of the onset of a green light. Thus, we expected that they helped participants recognize their available time of the onset of a green light before turning to an amber light, which could reduce the length of dilemma zone and assist their decision making (whether to go or stop) at intersections. In addition, the countdown-overlaid signal was expected to have better performance than the countdown-separated signal in terms of reaction time and satisfaction score, because the countdown indicator of the countdown-overlaid signal was overlaid with a green light. I.e., this feature may reduce driver's distraction in comparison with the countdown-separated signal which required drivers to simultaneously look at both its green lamp and auxiliary countdown display that was placed on the top of the green lamp.

As expected, the results showed that the two traffic signals with a countdown indicator improved driver's reaction time. The reaction times (mean = 0.46 sec) of the two signals with a countdown indicator were significantly shorter (mean difference = 0.21 sec) than that of the standard signal (mean = 0.67 sec). These results were consistent with previous studies reporting that reaction time could be reduced when the timing of an upcoming event is expected (Naatanen et al., 1974; Shinar, 2007). In addition, the countdown-overlaid signal was faster (mean difference = 0.06 sec) than the countdown-separated signal. This result satisfied our expectation. Abrams et al. (1989) elaborated this effect using saccadic eye movement that the eyes spend approximately 0.03 to 0.05 sec to locate interesting parts on the same line of sight. I.e., this effect may slow reaction time.

The reaction times of the right foot measured in the present study were slightly greater than reaction times reported in existing studies. The presents study measured the reaction time from the time when a green light turned to an amber light to the moment that a participant successfully pushed a brake pedal with the right foot. The mean reaction time of the three signals in this study was 0.53 sec that was larger than the reaction times (by as much as 15 to 40%) reported from similar studies (Pagaduan, 2015; Pfister et al., 2014). We assumed that this difference was primarily caused by task difference. Pagaduan (2015) and Pfister et al. (2014) employed a single choice-reaction task in order to observe genuine reaction time, while we used dual tasks (i.e., traffic signal observation during driving) in the present study. Aside from this reason, it is estimated that this might be affected by different definitions with respect to successful activation of a brake pedal.

The satisfaction score of the countdown-overlaid signal was slightly greater than that of the countdown-separated signal. In the debriefing session, participants explained the reason why the countdown-overlaid signal had better satisfaction scores than the countdown-separated signal. As expected, participants pointed that the countdown-overlaid helped reduce the number of observation targets during driving and thus their metal load during driving was mitigated as compared with the countdown-separate signal requiring swift eye movement between its green lamp and auxiliary countdown display.

In the present study, the counting number used for the countdown-overlaid and countdown-separated signals began from 5 (unit: sec) to avoid unnecessary driver distraction and provide a driver with a sufficient time for decision making before interactions. If the counting number is started from a larger number (e.g., 10), drivers may experience divided-attention for longer time, which often requires driver's eyes off the road. In addition, if the counting number is started from a smaller number (e.g., 3), it is likely to urge drivers to make their decision under time pressure. Although the present study employed the counting number from 5, an optimal number of the countdown still needs to be examined in the further study.

More ergonomic evaluations are needed to generalize the experimental results obtained in this study. First, this study conducted the experiments only for young college students. However, studies have revealed that human perception and motor skills are deteriorated by aging (Jung et al., 2011; Stevens, 1992; Verrillo and Gesheider, 1992; Cousins et al., 1998; Jiménez-Jiménez et al., 2011). Therefore, further testing is needed with participants in difference age groups in order to comprehensively investigate the effect of traffic signals with a countdown indicator. Second, field tests are required. The current study was conducted in simulated driving conditions to control environmental factors (i.e., road condition, weather condition) and to secure driver safety. However, field tests will help confirm the validity of the traffic signals with a countdown indicator and warrant their significance for the roadway safety.

Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Science, ICT & Future Planning; NRF-2016R1C1B1008150).

References

Abrams, R.A., Meyer, D.E. and Kornblum, S., Speed and accuracy of saccadic eye movements: characteristics of impulse variability in the oculomotor system. *Journal of Experimental Psychology*, 15(3), 529-543, 1989.

Behrendt, J., Untersuchungen zur Gelblichtproblematik an Knotenpunkten mit Lichtsignalsteuerung. Bundesmin. f. Verkehr, Abt. Straßenbau, 1970.

Bonneson, J. and Son, H., Prediction of expected red-light-running frequency at urban intersections. *Transportation Research Record: Journal of the Transportation Research Board*, (1830), 38-47, 2003.

Cousins, M.S., Corrow, C., Finn, M. and Salamone, J.D., Temporal measures on human finger tapping: Effects of age. *Pharmacology Biochemistry and Behavior*, 59(2), 445-449, 1998.

Chang, J. and Jung, K., Development of a press and drag method for hyperlink selection on smartphone. *Applied Ergonomics*, 65, 269-276, 2017.

Chin, H.C. and Quddus, M.A., Applying the random effect negative binomial model to examine traffic accident occurrence at signalized intersections. *Accident Analysis and Prevention*, 35, 253-259, 2003.

Gazis, D., Herman, R. and Maradudin, A., The problem of the amber signal light in traffic flow. *Operations Research*, 8, 112-132, 1960.

Jiménez-Jiménez, F.J., Calleja, M., Alonso-Navarro, H., Rubio, L., Navacerrada, F., Pilo-de-la-Fuente, B., Plaza-Nieto, J.F., Arroyo-Solera, M., García-Ruiz, P.J., García-Martín, E. and Agúndez, J.A.G., Influence of age and gender in motor performance in healthy subjects. *Journal of the Neurological Sciences*, 302, 72-80, 2011.

Jung, K. and Jang, J., Development of a two-step touch method for website navigation on smartphones. *Applied Ergonomics*, 48, 148-153, 2015.

Jung, K., Lee, M., Chang, J. and You, H., Evaluation of information presentation methods for a wearable braille display. *Journal of the Ergonomics Society of Korea*, 30(6), 739-747, 2011.

Li, Z., Zhang, J., Rong, J., Ma, J. and Guo, Z., Measurement and comparative analysis of driver's perception-eaction time to green phase at the intersections with and without a countdown timer. *Transportation Research Part F*, 22, 50-62, 2014.

Limanond, T., Prabjobok, P. and Tippayawong, K., Exploring impacts of countdown timers on traffic operations and driver behavior at a signalized intersection in Bangkok. *Transport Policy*, 17, 420-427, 2010.

Long, K., Liu, Y. and Han, L.D, Impact of countdown timer on driving maneuvers after the yellow onset at signalized intersections: An empirical study in Changsha, China. *Safety Science*, 54, 8-16, 2013.

Lum, K.M. and Halim, H., A before-and-after study on green signal countdown device installation. *Transportation Research Part F*, 9, 29-41, 2006.

Naatanen, R., Muranen, V. and Merisalo, A., Timing of expectancy peak in simple reaction time situation. *Acta Psychologica*, 38(6), 461-470, 1974.

Newton, C., Mussa, R.N., Sadalla, E.K., Burns, E.K. and Matthias, J., Evaluation of an alternative traffic light change anticipation system. *Accident Analysis and Prevention*, 29(2), 201-209, 1997.

Pagaduan, J.C., Reliability of an eye-foot reaction time test in chronojumpboscosystem. *Sport SPA*, 11(2), 15-18, 2015.

Pfister, M., Lue, J.L., Stefanini, F.R., Falabella, P., Dustin, L., Koss, M.J. and Humayun, M.S., Comparison of reaction response time between hand and foot controlled devices in simulated microsurgical testing. *BioMed Research International*, 1-8, 2014.

Polders, E., Daniels, S., Hermans, E., Brijs, T. and Wets, G., Crash patterns at signalized intersections. *Transportation Research Record: Journal of the Transportation Research Board*, (2514), 105-116, 2015.

Richards, C.M., Michaels, E.F. and Campbell, J.L., Driver attitudes and behaviors at intersections and potential effectiveness of engineering countermeasures. Washington, DC: U.S. Department of Transportation, Federal Highway Administration, Report No. FHWA-HRT-05-078, 2005.

Shinar, D., Traffic Safety and Human Behavior. ELSEVIER. Oxford: UK, 2007.

Stevens, J.C., Aging and spatial acuity of touch. *Journal of Gerontology*, 47(1), 35-40, 1992.

Verrillo, R.T. and Gesheider, G.A., Perception via the Sense of Touch in Tactile Aids for the Hearing Impaired. In Summers, I. R. (Ed). Tactile Aids for the Hearing Impaired. Willey, John & Sons, 1992.

Yi, Y., Kim, B., Kim, H., Lim, D., Bak, M., Min, B. and Min, Y., The CNS responses of elderly drivers due to signal types at the intersection: Focus on yellow interval dilemma situation. *Journal of the Ergonomics Society of Korea*, 29(5), 783-788, 2010.

Author listings

Joonho Chang: joonhochang@gmail.com
Highest degree: Ph.D., Industrial and Manufacturing Engineering, Pennsylvania State University, University Park
Position title: Regular Fellow at NIOSH, CDC
Areas of interest: Vehicle safety, ergonomic product design, occupational biomechanics, industrial safety and health, user interface design and evaluation

Kihyo Jung: kjung@ulsan.ac.kr
Highest degree: Ph.D., Industrial and Management Engineering, POSTECH
Position title: Associate Professor, School of Industrial Engineering, University of Ulsan
Areas of interest: Digital human simulation, Intelligent system design, User interface design and evaluation, Industrial safety and health