Evaluation of Cyclist Galvanic Skin Response and Visual Attention in Commercial Vehicle Loading Zones

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Abstract

With growing freight operations throughout the world, there is a push for transportation systems to accommodate trucks during loading and unloading operations. Currently, many urban locations do not provide loading and unloading zones, which results in trucks parking in places that obstruct bicyclist's roadway infrastructure (e.g., bicycle lanes). To understand the implications of these truck operations, a bicycle simulation experiment was designed to evaluate the impact of commercial vehicle loading and unloading activities on safe and efficient bicycle operations in a shared urban roadway environment. A fully counterbalanced, partially randomized, factorial design was chosen to explore three (3) independent variables: commercial vehicle loading zone (CVLZ) sizes with three levels (i.e., no CVLZ, Min CVLZ, and Max CVLZ), courier position with three levels (i.e., no courier, behind the truck, beside the truck), and with and without loading accessories. Bicyclist's physiological response and eye tracking were used as performance measures. Data were obtained from 48 participants, resulting in 864 observations in 18 experimental scenarios using linear mixed-effects models (LMM). Results from the LMMs model suggest that loading zone size and courier position had the greatest effect on bicyclist's physiological responses. Bicyclists had approximately 2 peaks-per-minute higher when riding in the condition that included no CVLZ and courier on the side compared to the base conditions (i.e., Max CVLZ and no courier). Additionally, when the courier was beside the truck, bicyclist's eye fixation durations (sec) were 1 second greater than when the courier was located behind the truck, indicating that bicyclists were more alert as they passed by the courier. The presence of accessories had the lowest influence on both bicyclists' physiological response and eye tracking. These findings could support better roadway and CVLZ design guidelines, which will allow our urban street system to operate more efficiently, safely, and reliable for all users.

Keywords: Commercial vehicle envelopes; Truck loading/unloading; Linear mixed effects model; Physiological responses; Eye tracking; Galvanic skin response (GSR).

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1. Introduction

With the presence of multiple modes sharing streets in urban areas, curb space has become a limited and high-demand commodity within the roadway network. Cities are responsible for deciding how curb space is managed, designed, and regulated for different transportation modes, including commercial vehicle parking and urban delivery activities. Factors that complicate curb space management include the high number of stakeholders and universally recognized urban planning policies (e.g., Smart Growth and Complete Streets) that promote compact development, mixed land-use and feasible multi-modal transportation options [1]. While these policies serve to improve the quality of life for residents and road users, they can often put bicyclists in danger by failing to acknowledge the potentially harmful interactions between this vulnerable road user group and commercial vehicles. Additionally, application standards do not support unique infrastructure necessities of freight activity and urban goods deliveries. These freight activities require the courier to walk around the vehicle, extend handling equipment and ramps, and maneuver goods; all of which require additional protected space beyond the dimensions of the vehicle, which is not accommodated by existing application standards.

Previous studies have found that curb use and demand by commercial vehicles is not met with adequate curb allocation [2-4]. Scenarios that illustrate the discrepancy between demand and supply include the parking of commercial vehicles on sidewalks, bike lanes, and turn lanes, extension of loading ramps and liftgates that impede crosswalks and sidewalks, and the staging of freight vehicles in locations that interfere with pedestrian and bicycle traffic. The conflicts with inadequate curb allocation for freight activity interfere with traffic operations and compromise the safety of both vulnerable road-users and the couriers. Studies in the United Kingdom found an annual rate of 70 fatalities and 2000 severe injuries in situations involving vehicles and the workplace, and a large proportion of these crashes happen during collections or deliveries [5]. Due to the absence of commercial vehicle loading zone (CVLZ) design standards in the United States, freight activity will continue to obstruct traffic flow and put couriers and vulnerable road users in danger.

To understand the implications of these truck operations, a bicycle simulation experiment was designed to evaluate the impact of commercial vehicle loading and unloading activities on safe and efficient bicycle operations in a shared urban roadway environment. To that end, no previous studies have been conducted that analyze the physiological response of bicyclists to events while monitoring both GSR and eye-tracking data. With the use of the bicycle simulator, the goal of this research is to overcome limitations from previous studies by controlling environmental and roadway conditions to more accurately quantify the relationship between physiological responses and certain environmental and roadway conditions. This study aims to determine how the size of the CVLZ influences the stress responses of bicyclists by observing the physiological response to the size of the loading zone, the presence and position of a courier, and the presence of loading zone accessories. While physiological responses do not directly indicate stress, these measurements can be used as surrogate data to gain a clearer understanding of how different CVLZ designs and conditions can trigger higher stimulation rates in riders and can provide guidance on future CVLZ design that accommodates bicyclists.

2. Methodology

OSU is home to a bicycling simulator which is comprised of an instrumented urban bicycle placed atop a stationary platform. When using the bicycle simulator, the user is presented with a display on a 3.24 m × 2.54 m screen with horizontal and vertical visual angles of 109° and 89°, respectively. The image resolution is 1024 × 768 pixels. Researchers build the virtual environment and observe bicyclist subjects from a workstation in an adjacent room that is separate from the room with the simulator.

The projected graphics have a refresh rate of 60 Hz. A 5.1 Logitech surround sound system is used to project ambient sounds around the bicycle while participants navigate the virtual environment. The computer system used is a quad-core host which runs Realtime Technologies *SimCreator Software* with a refresh rate that matches the graphics at 60 Hz. Performance measures including speed, positioning, braking, and acceleration are all captured with high accuracy using the simulator software (SimObserver). Software packages such as Internet Scene Assembler (ISA), Simcreator, and Blender were all used to develop the virtual environment. JavaScript-based sensors were used in ISA to create the simulated test track, which displayed dynamic objects, like a courier walking alongside the bicyclist.

The virtual environment was created to emulate a typical roadway containing varying types of commercial vehicle loading zones. The experiment used three cross-sections. The first cross-section included one roadway with two 3.65-meter travel lanes, two 1.84-meter bicycle lanes, and no loading zone. The second cross-section included a roadway with a 3.5-meter loading zone, two 3.65-meter travel lanes, two 1.84-meter bicycle lanes, and one small loading zone of 3.5-meter width. The third cross-section included a roadway with two 3.65-meter travel lanes, two 1.84-meter bicycle lanes and one large loading zone of 4.5-meter width.

Ambient traffic was coded manually to provide each participant with the same number of vehicle encounters and to limit the number of conflicts the participant experienced. To improve the experimental control, traffic was programmed to avoid passing the bicyclists during CVLZ interactions. All participants performed a calibration ride on the bicycle prior to beginning their experimental trial. Instructions were given to participants to abide by the traffic laws they typically would when bicycling. This calibration ride served to help participants adjust to the mechanics of the bicycling simulator and also helped determine whether participants were prone to simulator illness. Participants who experienced simulator sickness were removed from the study to limit their discomfort [6].

Galvanic Skin Response (GSR) is a measure of variation in sweat glands as a reaction to various stimuli initiated by events. A Shimmer3 GSR+ sensor was used to collect GSR readings in this study. The sensor was strapped to the wrists of participants, and the two electrodes were attached to the middle and ring finger of the non-dominant hand. The non-dominant hand remained stationary on the handlebars throughout the experiment, as to mitigate false-positive GSR responses. To ensure that the simulated events and GSR readings could be synchronized, a Logitech C920 HD Pro Camera was integrated to record the participant runs. Upon completion of the experiment, the GSR and video data were processed using iMotions software (V8.3).

Eye-tracking data were collected during the study which captured where participants looked while riding in the bicycling simulator. These data were collected using an ASL Mobile Eye-XG platform with a sampling rate of 30-Hz and an accuracy of 0.5–1.0° [7]. After collecting participants' eye-movement data, fixation and dwell data, all were analyzed by area of interest (AOI) polygons with the ETAnalysis software suite. Researchers watched each video segment that included navigation through the loading zone (i.e., 18 per participant). These video segments were cropped to the length of time (i.e., generally 10–30 seconds) that the bicyclist passed by the loading zone. Researchers drew AOI polygons on individual video frames in a sequence separated by intervals of approximately 5–10 frames. Targets were truck, courier, hand truck, and traffic. The ETAnalysis software was used to calculate the total fixation duration in seconds (TFD) data on each AOI.

A factorial design was used to allow for the observation of the three independent variables separately. The independent variables included in the experiment were pavement marking (3 levels), courier position (3 levels), and accessory (2 levels). Eighteen scenarios (3x3x2) were included in the factorial design, all of which were presented to participants. Five different tracks, each ranging from approximately 2 to 4 minutes, were used to fully counterbalance scenario order to control for carryover effects and practice. Each participant experienced a randomized grid sequence [8]. Two (2) dependent variables were observed in the experiment: GSR data and eye-tracking data.

50 participants (26 women, 24 men) participated in the simulator study. Participant ages ranged from 18 to 74 years which consisted of 24 women (M_{age} = 29.84, SD_{age} = 7.48) and 24 men (M_{age} = 36.45, SD_{age} = 15.57). In addition to the demographics, participants were asked other questions (i.e., bicycling experience, type of trips, level of comfort, etc) during the pre-ride survey [9].

To better understand the results, a Linear Mixed Effects Model (LMM) model was chosen for the analysis [10, 11]. The independent variables of loading zone size, courier position, and accessories were included in the model as fixed effects, while the subject variable was included in the model as a random effect.

3. Findings

As mentioned previously, two (2) measures of bicyclist performance were evaluated: GSR reading and bicyclist's visual attention. The GSR reading was calculated while the bicyclists navigated the commercial loading and unloading zones. Similarly, the bicyclist's eye-tracking data were analyzed from the point when the participant approached the loading zone and continued until the participant completely passed it.

GSR measurements were collected using a Shimmer3 GSR+ sensor and reduced down to provide average GSR peaks per minute for each individual and for the overall sample [12-15]. To develop the average peaks per minute, iMotions software (i.e., software used to process the GSR and video data) initially develops a baseline GSR reading for each participant based on their average responses throughout a scenario.

An LMM was used to estimate the relationship between the independent variables and participant's mean GSR reading (peaks per minute), which is appropriate given the repeated measures nature of the experimental design, where each participant experienced each scenario [12]. In addition, gender was also included in the model as an independent variable. These variables were included as fixed effects and participants' ID as random effects. The random effects were significant (Wald Z=4.21, $p < 0.001$), which suggests that it was necessary to treat the participant as a random factor in the model.

All independent variables, with the exception of accessories, were found to have a significant impact on the GSR reading of the bicyclists. Regardless the courier position and accessories, a bicyclist encountered with a parked truck in the maximum loading zone had the least GSR reading compared to minimum loading zone ($p = 0.001$) or no loading zone ($p = 0.049$). The second significant variable was courier position. When bicyclists rode in a scenario that had a courier on the side of truck, the participants had about 2 peaks/min more than the no courier condition (p = 0.026) and about 1.5 peaks/min more than when the courier was located behind the truck (p = 0.05). Gender was also considered in the analysis, as previous studies indicated that females have a higher level of stress when compared to males [16] when riding in uncomfortable conditions (i.e., unprotected bike lane). This finding matches with the LMM output. Regardless of other variables, females had 2 peaks/min more than males. Age was tested and found to be statistically not significant.

All possible interactions among the independent variables were also investigated. Regardless of accessories, on average, participants had higher GSR reading when the courier was walking alongside the truck with both no loading zone and minimum loading zone compared to maximum loading zone. The minimum loading zone size did not differ from the maximum loading zone size in terms of bicyclist performance measures. However, in the presence of a courier on the driver's side of the truck, the minimum CVLZ tended to be the most stressful scenario for bicyclists since they often veered from the bike lane toward the adjacent vehicular travel lane. Meanwhile, while holding the courier position and accessories constant, female bicyclists had higher GSR readings compared to males at all three loading zone sizes. A similar trend was observed when holding the pavement marking and accessory variables constant.

Furthermore, while the bicyclists traversed the loading zone area, the number and duration, in seconds, of participants' fixations on AOI (the truck/loading zone) were recorded, with a total fixation duration (TFD) of 0 seconds (indicating that the participant did not look at the target). The Average Total Fixation Duration (ATFD) was calculated by averaging all participants' total fixations using an AOI. A modeling approach similar to the one that was followed for the GSR reading was used to statistically examine differences in mean TFD. The LMM results showed that the presence of a hand truck is not statistically significant (p = 0.138), but the loading zone size is significant for both levels (p <0.001). Regardless of the courier position, this suggests that bicyclists fixate on the truck for exactly the same period for both conditions with or without a hand truck. The random effect was statistically significant (Wald Z=4.10, p <0.001). Interestingly, participants encountering no loading zone or minimum loading zone were spending a longer time (i.e., approximately 0.5 seconds) observing the truck (p <0.001) as compared to the maximum loading zone. This suggests that bicyclists had enough time to scan the surroundings while passing the maximum loading zone instead of fixating on the truck. One possible interpretation of this observation is that bicyclists felt more comfortable driving along the maximum loading zone than having a commercial vehicle parked exactly at or beside the bike lane.

Additionally, TFD of bicyclists on courier and traffic was also calculated. Bicyclists fixated more on the courier when walking alongside the truck compared to when the courier was behind the truck. One possible interpretation of this observation is that bicyclists may have worried that they would hit the courier, so they kept glancing at the driver until the loading zone was passed. In general, bicyclists spent a longer time observing the courier when they encountered no loading zones or minimum loading zones. This finding supports the GSR results; hence, bicyclists felt uncomfortable riding along a commercial vehicle parked exactly at or beside the bike lane. The mean TFD on the traffic was higher when the truck was obstructing the bike lane compared to the minimum and maximum CVLZ. This result fits, as bicyclists were observing the traffic constantly to find a gap and use the travel lane.

4. Conclusions

Depending on the desired bicyclist response when approaching truck loading/unloading activities, different recommended treatments could be distinctly effective based on the output of the bicycling simulator experiment. The bicyclist's GSR reading and visual attention performance measures were used to evaluate alternative engineering treatments. Results from both devices match with each other and show that the no-loading zone condition (i.e., when truck obstructs the bike lane) and the courier on the driver's side generated a higher GSR reading and limited visual search patterns, as bicyclists are trying to shift their position toward the left edge of the bike lane and into the adjacent travel lane, while avoiding conflict with other transportation modes. The extra buffer in the CVLZ for the courier impacts bicyclists' performance measures positively; therefore, providing enough buffer for the courier to move around the vehicle is recommended. What this research shows is that the more visual attention yielded by bicyclists directly correlates with physiological responses, indicating that visual attention could be an indicator of a bicyclists' comfort level while riding. This type of result can also be seen in other areas of transportation where pedestrians may yield higher levels of stress when focusing (i.e., higher eye fixations) to find gaps in traffic while crossing the street.

Results show that bicyclists were less comfortable and had less visual scanning while riding in the minimum loading zone condition, especially when the courier was on the driver's side. One possible solution could be placing barriers on the left side of the bike lane to prevent the interaction between bicyclists and traffic from the travel lane. Additionally, in situations where only a minimum loading zone could be designed due to space restrictions, the courier should minimize the time they occupy the bike lane to move along the vehicle and use the passenger side (i.e., similar to UPS drivers design, where they use the passenger door to load/unload the vehicle). Furthermore, policy considerations regarding the width of the bicycle lane are recommended. Jashami et al. (2020) found that lateral distance deviations exceeded the width of the bicycle lane in the scenario where the truck was

parked in the minimum loading zone, which indicates that bicyclists were using the traveled way (i.e., outside of the bicycle lane) to bypass or navigate around the truck, and ultimately putting themselves in unsafe scenarios [9]. If bicyclists react to this scenario and require space outside of the bicycle lane to feel safe when passing a truck, this could justify the need to increase the width of a bicycle lane when a minimum loading zone is present.
In states where bicyclists are permitted to use the sidewalk for riding, access for the sidewalk should be designed to accommodate bicyclists when a delivery truck is anticipated to obstruct the bike lane due to loading/unloading activities. Thus, placing an additional curb ramp upstream of the CVLZ is recommended to allow the bicyclist to transition to the sidewalk, if legally permitted. The downside of this recommendation is the potential risk generated from the interaction between bicyclists and pedestrians. The present study is not without limitations. The simulation and design were based on commercial vehicle parking designs in the United States and would likely have to be adjusted to be applicable to other cities and countries throughout the world. The results from this study could support better roadway and commercial vehicle loading zone design guidelines, which will allow our urban street system to operate more efficiently, safely, and reliably for all users.

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