QUANTIFYING AGGRESSIVE DRIVING BEHAVIOR AT SIGNALIZED INTERSECTIONS USING A DRIVING SIMULATOR

Mazen Danaf
Graduate Student
Department of Civil and Environmental Engineering
American University of Beirut
104 Bechtel
American University of Beirut
Phone: +961-1- 350000
Fax: +961-1-744462
Email: msd14@aub.edu.lb

Maya Abou-Zeid
Assistant Professor of Civil and Environmental Engineering, American University of Beirut
2M3 Bechtel
Phone: +961-1- 350000 x 3431
Fax: +961-1-744462
Email: ma202@aub.edu.lb

Isam Kaysi
Professor of Civil and Environmental Engineering, American University of Beirut
307 Bechtel
Phone: +961-1- 350000 x 3471
Fax: +961-1-744462
Email: isam@aub.edu.lb

ABSTRACT

Aggressive driving behavior is often caused by frustrating events. It is manifested through violations such as running red lights and stop signs, engaging in risky behavior such as weaving in and out of traffic and accelerating rapidly, and other hostile actions such as honking and making rude gestures. This study utilizes a driving simulation experiment and a post-driving survey in order to examine the effect of three frustrating events at signalized intersections on aggressive driving behavior of university students. In the first event, drivers encounter a short green phase which starts and ends before they arrive at the intersection. In the second event, drivers miss a green light because the intersection is blocked by other vehicles in the perpendicular direction. In the third event, other vehicles violate a red light while the driver is at the same intersection. The experimental results indicated that these three events encourage subjects to violate red lights and engage in risky behavior after the intersection such as speeding, accelerating, and weaving in and out of traffic. In addition, driving aggressiveness increases as subjects witness more frustrating events. No significant differences in speeding, accelerating, or the likelihood of violating red lights were observed between males and females or based on student age. However, significant differences were observed between violators and non-violators in terms of speed and the extent of pedal depression. It was also observed that violators, males, and younger drivers are more likely to use the honk. The post-driving survey responses confirmed these results, with a higher likelihood to engage in violations and risky driving behavior being reported by those who violated red lights in the simulation. In addition, positive correlations were found between the survey responses related to risky driving and driving anger on one hand, and the extent of speeding and accelerating on the other hand. This research highlights the importance of proper signal timing settings, "do not block intersection" signs and fines, and strict enforcement of traffic regulations as policy instruments to reduce aggressive driving behavior and increase road safety.

Keywords: aggressive driving, signalized intersections, driving simulator, traffic safety.

INTRODUCTION

Aggressive driving, a direct outcome of driving anger, is a major cause of driving accidents. It was defined by the director of the National Highway Traffic Safety Administration, Ricardo Martinez, as "a combination of moving traffic offenses so as to endanger other persons or property". Martinez added that driving behavior associated with aggressive driving accounts for one third of the crashes, and two thirds of the resulting fatalities (Martinez, 1997).

Most of the past research has approached the topic of driving aggressiveness either by relying on the state-trait anger theory stated by Spielberger in 1988 (See for example Deffenbacher et al., 2000, Nesbit et al., 2006, etc.), or by relying on the instrumental-hostile classification of aggressive behavior explained by Baron and Byrne in 1994 (See for example Shinar, 1998, Laujen and Parker, 2001, Hamdar et al., 2008, etc.).

Deffenbacher et al. (2000) extended Spielberger's definition to include driving anger. They defined trait driving anger as an individual's tendency to be provoked while driving, and thus engage more in risky behavior, while state anger was defined as a function of trait driving anger and the presence of provocative events. Thus, trait anger is considered to be a characteristic of the individual only, while state anger is dependent on the events experienced while driving.

Based on the classification of aggressive behavior stated by Baron and Byrne (1994), David Shinar defined "instrumental" driving aggressiveness as the driving behavior which the aggressor assumes will help him/her overcome a frustrating obstacle and move ahead, such as honking the horn at drivers blocking the path, weaving in and out of traffic, and violating red lights. On the other hand, "hostile" driving behavior helps the aggressor "feel good" without actually resolving the problem, such as cursing at other drivers and honking the horn at pedestrians (Shinar, 1998).

Driving aggressiveness is often manifested by several traffic offenses including running red lights. In a report published by the NHTSA, a total of 9,951 vehicles were involved in fatal crashes at intersections in the United States in 1999 and 2000, and 20% of these vehicles failed to obey traffic signals (NHTSA, 2004). Certain events occurring at signalized intersections can elicit driving anger and encourage drivers to violate red lights. This study focuses on three frustrating scenarios which occur frequently at intersections in Beirut. The first scenario describes the situation whereby a driver encounters a short green phase which starts and ends before he/she arrives at the intersection. The second scenario represents the situation where a driver is prevented from traversing the intersection during a green phase due to the presence of vehicles blocking the intersection in the perpendicular direction until the signal light turns red again. The third scenario represents the situation where the subject sees other vehicles violating red lights. The first two scenarios have direct implications on signal timing, while the second and third scenarios have implications on enforcement. This research aims at testing three main hypotheses. First, the occurrence of these events will encourage drivers to violate red lights and maintain aggressive driving behavior even after traversing the intersection. Second, this aggressiveness will increase incrementally as drivers encounter more frustrating events. Third, drivers with self-reported trait driving anger are more likely to engage in risky behavior and violate red lights.

To test these hypotheses, a sample of students from the American University of Beirut (AUB) is recruited to participate in a driving simulator experiment replicating the events mentioned above, and then asked to fill out a post driving survey about their typical driving behavior and attitudes towards driving.

The remainder of this paper is organized as follows. Section 2 reviews some of the previous research focusing on aggressive driving behavior. Section 3 describes the driving simulator used in this study. Section 4 describes the design of the experiment that was conducted, and Section 5 describes the data collection procedure and the sample. Section 6 presents the obtained results and the corresponding analysis. Finally, section 7 concludes the paper and presents possible extensions of this research.

LITERATURE REVIEW

Aggressive driving and road rage have been studied extensively by transportation engineers and psychologists. Some of the studies relied on filed observations and tests, while others utilized driving simulators. This section reviews some of these studies: their methods, hypotheses, and major findings.

Observational/field Studies

Some studies focused mainly on engineering related variables as predictors of aggressiveness such as the geometric features of roadways and intersections and the properties of surrounding traffic, with minimal focus on individual characteristics. Hamdar et al. (2008) used structural equation modeling (SEM) in order to develop an aggressiveness propensity index (API) for signalized intersections. The authors used data collected from 10 signalized intersections in the greater Washington DC metropolitan area. The observed exogenous variables used in modeling the aggressiveness index included the flow rates at the intersections, frequency of pedestrian crossings, number of heavy vehicles, queue lengths, number of lanes, intersection angles, intersection grades, signal timing, presence of bus stops, land use types, presence of enforcement measures, startup delay, number of lane changes, and the gap acceptance values. The data was then reduced into five factors (traffic performance dimension, intersection geometry dimension, signal timing, law enforcement dimension, and transit dimension). Shinar (1998) studied aggressiveness at signalized intersections in terms of running red lights and honking the horn. He focused on the relationship between these two variables on one hand, and the length of the red and green phases and the setting on the other hand. Shinar reported higher violation rates at congested intersections, intersections with short green phases, intersections with long red phases, and intersections with long waiting times. Shinar also measured honking delay, defined as the time until a subject honks the horn at a car that does not begin to move when the traffic signal light changes to green. He reported shorter honking delays at intersections with short green phases. In addition, honking delays were shorter during the rush hours compared to the weekend, and shorter in urban congested environments compared to other places. Kaysi and Abbany (2007) modeled aggressive driving behavior at unsignalized intersections in Beirut. The authors observed gap acceptance and merging at U-turns and distinguished between normal merging and aggressive merging, which occurs when the driver forces his/her vehicle into opposing traffic. A probit model predicting the probability of aggressive merging was then developed. The results indicated that age, car type, and the average speed of the major traffic were important predictors of aggressive merging.

On the other hand, some studies focused merely on individual characteristics and other factors as predictors of aggressive driving behavior without addressing the effect of engineering or design features. Porter (1999) studied signal violation events focusing on drivers who run red lights. He concluded that these drivers do not have to be "typical" aggressive drivers. However, they usually engage in tailgating, weaving in and out of traffic, speeding excessively, and gesturing angrily at other drivers. Porter stated several factors that appeared to be correlated with running red lights such as driver's age and gender (younger drivers and males are more likely to run red lights), vehicle occupancy, driving time, driving destination, driving distance, driver's socio-economic status and driver's education level. He also concluded that red light violators do not have to be frustrated when performing the corresponding illegal maneuvers. Doob and Gross (1968) studied horn-honking responses at intersections. Subjects were asked to drive through a signalized intersection, and were unaware that they were under observation. These subjects were delayed for 15 seconds after the signal light had turned green, either by a luxury (high status) vehicle, or an old (low status vehicle). The results indicated that subjects were less likely to honk at the high status vehicle. In addition, males tended to honk faster than females in both conditions.

Driving simulator studies

Driving simulators provide an adequate environment for studying driving anger and aggressiveness, since they enable researchers to collect comprehensive data about the driver and the context, and to perform safe and controlled experiments. Lee (2010) studied the effect of time pressure, in-vehicle distractions (phone messages), and out-of-vehicle distractions (pedestrian detection) on aggressive driving behavior in a driving simulator experiment designed with frustrating events. Lee considered age as the most significant factor affecting safe driving and awareness. The results showed that older drivers kept a safer distance from leading vehicles, detected more pedestrians, and reported less anger and frustration compared to younger drivers. Similarly, Deffenbacher et al. (2003) performed another simulator experiment with frustrating events to compare high anger and low anger drivers. These were classified based on the Driving Anger Scale Questionnaire (DAS). The results showed that high anger drivers exhibited higher physical and verbal aggression, had higher collision rates, and had shorter time-to-collision values. They also concluded that gender is related to speed, but not to anger. In another simulator experiment, Ellison-Potter and Deffenbacher (2001) studied the effects of anonymity (when subjects cannot be identified) and aggressive stimuli (e.g. violent signs) on aggressive driving. They concluded that these two factors, in addition to trait anger, caused drivers to have more collisions, hit more pedestrians, drive at higher speeds, and run red lights more frequently. In addition, males drove at higher speeds, had more accidents and pedestrian hits, and ran red lights more than females, while females engaged more in indirect aggression (e.g., treating someone condescendingly). Other simulator studies focused on the effect of different factors on driving aggressiveness such as passion for driving (Philippe et al., 2009) and driving dislike (Matthews et al., 1998).

Summary

Based on the above studies, design factors, individual characteristics, and frustrating events appeared to influence aggressive driving behavior significantly. However, it is difficult to study the combined effects of these variables due to several factors. First, it is difficult to develop controlled experiments on the roads. Other exogenous variables or events might affect the behavior of different drivers, since the researchers cannot fully control the environment. Second, it is challenging to collect comprehensive data about the environment, the context, and the driver in real life driving. This research provides an opportunity to study these combined effects simultaneously in addition to the effect of the incremental increase of aggressiveness, in a safe, controlled, replicable, and inexpensive environment through the use of driving simulation. It also focuses on students, since they belong to the age group that is most likely to engage in risky and aggressive driving. This research aims at recommending policies or engineering interventions aimed at reducing aggressive driving behavior and thus enhancing road safety.

DRIVING SIMULATOR DESCRIPTON

The driving simulator that is used in this research is the DriveSafety DS-600c Research Simulator housed at a laboratory in the Civil and Environmental Engineering department of the American University of Beirut. It consists of a full-width Ford Focus automobile cab with standard driver controls and instrumentation and some motion cues. The view is projected onto a 180° display screen, which allows for an immersive driving experience. This simulator is categorized as a mid-level simulator. Mid-level simulators are accepted as valid research tools since they often guarantee relative validity and sometimes absolute validity compared to real world driving (Fisher et al., 2011, Hoskings and El-Gindy, 2006). According to Blaauw (1982), relative validity is established when the two systems generate differences in the same direction, and having a similar or identical magnitude, while absolute validity is achieved when the two systems produce results with the same numerical values.

The authoring tool “HyperDrive” is used to design a wide range of scenarios. Scenario authors have the ability to choose the type of topography and land use among several options (urban, suburban, rural, hilly, etc.), to control weather and time-of-day conditions, to specify the geometric and design features of the context (types of roadways and intersections, number of lanes, etc.), and to control the occurrence of events such as changes in signal phases and the actions of other vehicles and pedestrians on the road. These events are initiated whenever the subject or another entity is within a certain distance from a “trigger”. Different triggers cause different events to occur (e.g. a signal light turns red, a vehicle moves along a specified path, a sound message is delivered, etc.).
Several variables are recorded at user-defined regular intervals (e.g. 0.1 seconds) throughout the simulator drive and are stored in an accessible data file. These variables include the trajectory, speed, lateral and longitudinal acceleration, extent of pedal depression, lateral position, headway, collision state, honk state, and other variables.

EXPERIMENTAL DESIGN

The experimental procedure consists of four phases: an introductory phase where subjects are asked to fill out a screening interview and a consent form, a practice phase where subjects are asked to drive the simulator for a short training session, the driving simulator experiment, and finally a post-driving survey.

Introductory phase

The purpose of this phase is to screen eligible subjects, introduce them to the experiment/context, and provide them with the necessary briefing. The screening interview is used to verify that the subjects are physically, mentally, and legally eligible to drive and participate in the experiment. Subjects are asked whether they suffer from certain diseases, illnesses, or disorders that prevent them from driving. Moreover, they are asked whether they have a driving license and whether they currently drive. The consent form includes information about the experiment: the setting, the purpose, and the potential risks. Subjects are not informed about the exact purpose of the experiment (studying aggressive driving particularly); however, they are told that the objective is to study driving behavior in general. Participants are asked to read the consent form carefully and sign it.

Practice phase

After filling out the screening interview and the consent form, drivers are asked to drive the simulator-vehicle for a short practice session. This part of the study is necessary in order to familiarize the subjects with the simulator and to make sure that they do not suffer from simulator sickness while driving. In this phase, subjects drive in a suburban environment (similar to that of the actual experiment) with light traffic and no unexpected or frustrating events. Subjects are told that they have the freedom to go anywhere, and asked to drive as they do in real life. The duration of the practice session is 5 minutes (although it was sometimes extended based on subjects' requests who felt they needed more time to familiarize themselves with the simulator).

Simulator experiment

After practicing, subjects are informed that the next session involves data collection, and that they are expected to drive in the same manner they do in real life: without colliding with other vehicles or objects and without moving off the road. They are also informed that they are expected not to violate traffic regulations.

The experiment takes place in a suburban setting, where typical buildings and houses are placed on both sides of the road. Weather conditions are unexceptional (without any fog, rain, or wind) and visibility is not cut off by any barriers or obstructions. Subjects are supposed to drive in straight roadway sections with two lanes in each direction, and with a posted speed limit of 30 miles per hour. Speed limit signs are placed regularly after each intersection. Double yellow lines are placed between the two directions of traffic flow. No parked cars, pedestrians, or other objects are placed on the road.

Driving directions are provided through sound messages and billboards placed before intersections (displaying texts such as: “Turn Right”, “Turn Left”, or “Continue Straight”).

The subjects are expected to drive through 9 consecutive intersections spaced at 800 meters each. No ambient traffic is set in the driver's traffic direction, which gives the driver the total freedom to maneuver, change lanes, and violate red lights. Light traffic is present in the opposite direction. Subjects drive for 600 meters before arriving at the first intersection. All intersections are signalized, and they are perpendicular and full (four-leg) intersections.

The first intersection is designed as a control intersection. No exceptional events take place except for the signal state changing from green to yellow, then red before the subject arrives. Traffic in the opposite direction will stop at the red light.

Each of the second, third, and fourth intersections involves a single exceptional event. Three events are designed and each is assigned to one of these three intersections only. However, the pattern in which the events are ordered differs among drivers, resulting in 6 different combinations (each subject will experience a different combination).

In the first event, the subject approaches a signalized intersection and sees a red light. The signal state turns green 300 meters before the subject arrives for a short duration, and then turns red 100 meters before the subject arrives. The duration of the green phase typically ranges between 5 and 7 seconds depending on the subject's speed.

In the second event represented in Figure 1 below, the subject approaches a signalized intersection where the light turns yellow before he/she arrives. Two vehicles approach the subject from behind and pass him/her, violating the red light. Moreover, some vehicles in the opposite direction violate the red light too. The violating vehicles in the subject's direction take a right turn into a minor road after crossing the intersection in order not to interfere with the following scenarios.

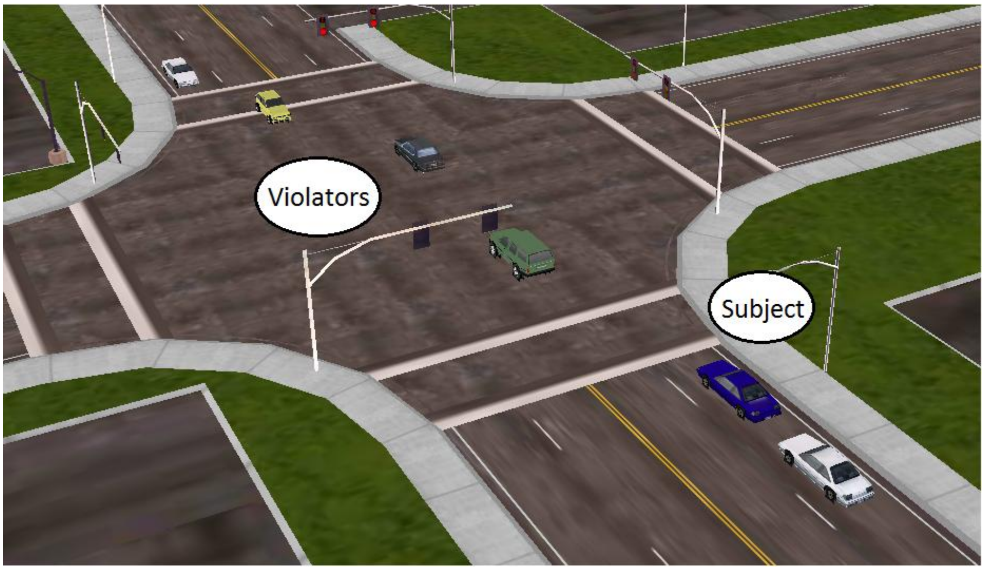

Figure 1 – Violations scenario

In the third event represented in Figure 2 below, the subject arrives at an intersection where the light turns red. Vehicles will then start flowing in the perpendicular direction in a congested way. When the signal turns green again in the subject's direction, the road will be blocked by vehicles until the driver sees the red light again when the road will be cleared.

Figure 2 – Blocked intersection scenario

The fifth intersection is signalized too, but the signal is always green. This is to ensure that the experiment feels realistic to drivers, and that they do not encounter red lights consecutively. The seventh intersection is similar to the fifth intersection.
The sixth and ninth intersections are similar to the first one; no exceptional events take place. These are used mainly to compare the behavior of subjects between these intersections and

the first, in order to analyze the effect of the incremental aggressiveness that is caused by the previous events experienced by subjects.

The eighth intersection involves two of the events described before. For each combination of these events (at the second, third, and fourth intersections), the eighth intersection will include the first two events combined. Therefore, the subject can either experience a short green interval followed by signal violations by other vehicles, a short green interval and vehicles in the perpendicular direction blocking the intersection, or vehicles in the perpendicular direction blocking the intersection followed by violations by other vehicles in the subject's direction.

Based on the above, intersections 1, 6, and 9 are control intersections while intersections 2, 3, 4, and 8 are treatment intersections. In all of these situations (except at intersections 5 and 7 where the lights are always green), the driver will have a choice whether to violate a red light or not.

Post-driving survey

After completing the simulator experiment, subjects are asked to fill out a survey. Subjects are asked about their driving behavior in general, driving characteristics, emotions experienced on the road, how often they perform specific actions while driving, and how they react to certain scenarios or events occurring on the road. The survey is divided into four sections. In the first section, drivers are provided with statements about their driving attitudes and habits and asked to answer whether they agree or disagree with these statements on a scale of one to five (strongly disagree, disagree, neither agree nor disagree, agree, and strongly agree). In the second section, subjects are asked how often they undertake certain actions on a scale of one to five (never, rarely, sometimes, often, and always). Most of the questions in these two sections are obtained from commonly used surveys such as the Dula Dangerous Driving Index (DDDI) (Dula and Ballard, 2003), the Driver Stress Inventory (DSI) (Matthews et al., 1997), and the Driving Behavior Questionnaire (DBQ) (Reason et al., 1990). Some of these questions have been modified in order to be consistent with the objectives of the experiment and the expected characteristics of the sample. In the third section, subjects are asked about their socio-demographic characteristics, how often they drive, what type of vehicle they drive, and their previous crash and ticket history. In the fourth section, drivers are asked about their experience in the driving simulator (how realistic it was and whether they felt dizzy or suffered from simulator sickness) and about any additional comments related to the experiment.

The questions in the first two sections are presented in Table X and Table XI in Appendix A.

DATA COLLECTION AND SAMPLE DESCRIPTION

Recruitment for the experiment was mainly based on flyers distributed all over the AUB campus, or distributed to students entering/leaving the AUB main gate. In addition, some subjects were recruited by personal approaching.

Subjects were allowed to participate in the experiment if they were AUB students, they had obtained a driving license, and they were current drivers, unless they suffered from a medical situation that prevented them from driving the simulator (dizziness, motion sickness, heart diseases, sleep deprivations, pregnancy, etc.).

A total of 100 AUB students volunteered for the experiment. However, 2 subjects felt extremely dizzy and withdrew from the experiment in the training session, and 2 other subjects were dropped from the experiment for not taking it seriously.

From the remaining 96 subjects, 15 subjects were removed from the analysis later either because they had accidents during the drive (9 students), they were over-speeding and missed the occurrence of a scenario (5 students), or because they did not follow the posted road directions (1 student). Most students who had accidents were trying to penetrate the vehicles in the perpendicular direction in the blocked intersection scenario. These students were removed from the analysis because their whole driving patterns changed after having the accident since they became more alarmed. Students who missed a scenario were removed from the analysis to maintain consistency across subjects. As for the student who did not follow road directions, the run was terminated automatically after reaching a dead end.

The remaining sample consisted of 81 students, 62 of whom are males and 19 are females. Ages ranged between 18 and 29. Most students were between 18 and 21 years old (24, 19, 15, and 11 students, respectively), while 11 students were between 22 and 25, and only one student was 29 years old. The overall duration of the experiment ranged between 30 and 45 minutes. The time to complete the simulator drive ranged between 10 and 15 minutes.

RESULTS

Based on the results from the previous studies, aggressive driving behavior is expected to be manifested through red light violations (e.g. Shinar, 1998), speeding, accelerating, weaving in and out of traffic (e.g. Porter, 1999), honking the horn (e.g. Shinar, 1998, Doob and Gross, 1968), and having lower time-to-collision values (e.g. Deffenbacher et al., 2003).

The results of this experiment were obtained from the simulator output (with a frequency of 10 readings per second) and the post-driving survey. The simulator results were classified into post-intersection results, which were recorded in the 400-meter stretches after each intersection. These include the average and maximum speed, average and maximum pedal depression (a value ranging from zero to one where zero indicates that the gas pedal is not being depressed, and one indicates that this pedal is at the maximum depression), and the standard deviation in lateral position. On the other hand, pre-intersection measures were recorded starting from the moment the traffic light turns red, and until the subject reaches the intersection. These include honking and time-to-violation. Some of these results are presented in Table I below:

Table I – Violations and output measures at successive intersections

Intersection Number	Number of Red Light Violations	Std. Dev. in Lateral Position	Avg. Speed	Max. Speed	Avg. Pedal Depression	Max. Pedal Depression
Intersection 1 (control)	0	0.22	16.97	19.31	0.15	0.33
Intersection 2 (treatment)	2	0.26	18.15	20.95	0.20	0.42
Intersection 3 (treatment)	4	0.26	18.25	21.29	0.21	0.42
Intersection 4 (treatment)	8	0.29	18.79	22.08	0.23	0.43
Intersection 6 (control)	1	0.23	19.06	22.60	0.26	0.45
Intersection 8 (treatment)	5	0.31	18.41	21.66	0.23	0.43
Intersection 9 (control)	8	0.25	18.72	21.97	0.23	0.41

Red light violations

A total of 28 violations were recorded at all intersections (4.9% of potential violations), and 19 out of 81 drivers (23.4%) were violators (violated at least one red light). Out of the 28 violations, 21 were made by males and 7 were made by females. Male violators were 15 (24% of males) compared to 4 female violators (21% of females). Gender did not seem to have a major effect on the likelihood to violate red lights.

Similarly, the effect of age was not evident. Drivers were classified into two age groups: young drivers, who are 18 or 19 years old (43 out of 81 subjects) and older drivers, who are 20 years old or more (38 subjects). Ten of the younger drivers were violators (23.3%) compared to 9 older violators (23.7%). A total of 14 violations were committed by each of young drivers and old drivers.

The impact of the three frustrating events (short green, blocked intersection, or violations by other vehicles) on the number of violations was obvious. At the first intersection which is a control intersection, no violations were observed. This is because drivers were not subjected to any frustrating events yet.

At the second, third, and fourth intersections, drivers encountered the three events mentioned above, and consequently several violations were observed. In addition, the number of violations at the fourth intersection was higher than that at the third, while that at the second intersection was the lowest. Thus, the effect of the incremental increase of aggressiveness can be confirmed. Moreover, violations by other vehicles caused 6 violations, compared to 4 violations caused by each of the short green phase and the blocked intersection events.

At the sixth intersection which is also a control intersection, only one violation was observed.

Five violations were observed at the eighth intersection, whereby drivers encountered a combination of two frustrating events.

Surprisingly, eight violations were observed at the final intersection despite the fact that it is also a control intersection. This can be explained by the occurrence of two frustrating events at the previous intersection. The occurrence of one violation at the sixth intersection (second control intersection) and 8 violations at the last control intersection confirm the incremental intensification of aggressiveness.

Lateral deviation, speed, and pedal depression

The effect of frustrating events can be also confirmed by studying the lateral deviations. The average standard deviation in lateral position is the lowest at the first intersection. At the following three intersections, the values are significantly higher. The average value at the second control intersection is lower than the three preceding values, but still higher than that at the first control intersection. The highest values are observed at the eighth intersection, where two frustrating events take place. The values decrease again at the final intersection (third control intersection), but maintain a value which is higher than the values at the first and second control intersections.

The average and maximum values of speed and pedal depression increase as the subjects move from one intersection to another. The obtained values at the first intersection are the lowest since it is a control intersection with no frustrating events. The differences are mostly significant between the first intersection and the second, where drivers first encounter a frustrating event. The increasing trend in these values is maintained until reaching the sixth intersection, where the highest values are observed. The values are lower at the eighth intersection despite the occurrence of two frustrating events. A possible explanation for this decrease might be the absence of frustrating events at the three preceding intersections (a control intersection and two intersections with green lights). Another possible explanation might be that subjects have expected these events since they have already experienced them, and therefore their impact was smaller compared to witnessing these events for the first time. However, the values increase again at the final control intersection (except for the maximum pedal depression).

The effect of gender and age on these variables was not significant. As indicated in Table II, the t-test showed that the differences between males (56 subjects) and females (19 subjects) are not significant at the 95% confidence level for any of these variables at all seven control and treatment intersections, except for the standard deviation in lateral position at the third and eighth intersections only, where males had higher deviations compared to females.

Table II – Differences between males and females at each intersection (Females/Males (t-stat))

Intersection Number	Std. Dev. in Lateral Position (m)	Avg. Speed (m/s)	Max. Speed (m/s)	Avg. Pedal Depression (dimensionless)	Max. Pedal Depression (dimensionless)
Intersection 1	0.19/0.23 (1.08)	18.2/16.6 (1.33)	21.0/18.8 (1.44)	0.20/0.14 (1.54)	0.40/0.32 (1.61)
Intersection 2	0.24/0.27 (0.63)	19.5/17.7 (1.44)	22.9/20.4 (1.47)	0.26/0.18 (1.35)	0.46/0.41 (0.81)
Intersection 3	0.19/0.28 (2.69)	19.5/17.9 (1.31)	23.2/20.7 (1.43)	0.28/0.19 (1.40)	0.45/0.42 (0.51)
Intersection 4	0.21/0.32 (1.42)	20.0/18.4 (1.17)	23.9/21.5 (1.28)	0.29/0.22 (1.36)	0.48/0.42 (0.87)
Intersection 6	0.27/0.22 (0.84)	20.3/18.7 (1.17)	24.7/22.0 (1.45)	0.35/0.23 (1.79)	0.53/0.43 (1.37)
Intersection 8	0.21/0.33 (2.28)	19.9/17.9 (1.6)	24.0/20.9 (1.66)	0.30/0.20 (1.62)	0.47/0.42 (0.83)
Intersection 9	0.21/0.26 (1.6)	20.3/18.2 (1.53)	24.3/21.2 (1.7)	0.28/0.21 (1.26)	0.44/0.40 (0.72)

Similarly, when comparing younger drivers aged 18 or 19 (43 subjects) to older drivers aged 20 and above (38 subjects), the t-test shows that no significant differences exist between the two age groups except for pedal depression at the first intersection and lateral deviations at the sixth intersection, where younger drivers had higher values as indicated in Table III below.

Table III – Differences between age groups at each intersection (young drivers/older drivers (t-stat))

Intersection Number	Std. Dev. in Lateral Position (m)	Avg. Speed (m/s)	Max. Speed (m/s)	Avg. Pedal Depression (dimensionless)	Max. Pedal Depression (dimensionless)
Intersection 1	0.20/0.24 (0.75)	17.6/16.3 (1.37)	20.2/18.3 (1.65)	0.18/0.12 (1.98)	0.38/0.29 (2.52)
Intersection 2	0.30/0.22 (1.75)	18.7/17.5 (1.19)	21.6/20.2 (1.09)	0.23/0.17 (1.28)	0.44/0.39 (1.03)
Intersection 3	0.21/0.31 (1.82)	18.5/18.0 (0.43)	21.7/20.8 (0.59)	0.24/0.19 (1.29)	0.45/0.39 (1.14)
Intersection 4	0.37/0.20 (1.5)	19.3/18.3 (0.89)	22.7/21.4 (0.89)	0.26/0.20 (1.25)	0.46/0.40 (1.05)
Intersection 6	0.26/0.19 (2.09)	19.4/18.6 (0.68)	23.5/21.6 (1.12)	0.29/0.22 (1.44)	0.49/0.40 (1.53)
Intersection 8	0.31/0.30 (0.06)	19.0/17.7 (1.22)	22.6/20.6 (1.32)	0.26/0.19 (1.55)	0.47/0.38 (1.53)
Intersection 9	0.27/0.23 (0.73)	19.1/18.3 (0.76)	22.9/20.9 (1.32)	0.26/0.19 (1.67)	0.46/0.36 (1.95)

Significant differences were observed between violators (19 subjects) and non-violators (62 subjects), as indicated in Table IV below. Violators drove significantly faster, and pushed the gas pedal more after all seven intersections. However, the differences in lateral deviations were not significant at the 95% confidence level except at the sixth intersection where violators had higher deviations. These results are in accordance with Porter's (1999) findings, where he stated that red light violators are likely to engage in speeding.

Table IV – Differences between violators and non-violators at each intersection (violators/non-violators (t-stat))

Intersection Number	Std. Dev. in Lateral Position (m)	Avg. Speed (m/s)	Max. Speed (m/s)	Avg. Pedal Depression (dimensionless)	Max. Pedal Depression (dimensionless)
Intersection 1	0.32/0.19 (1.67)	19.1/16.3 (2.48)	22.6/18.3 (2.85)	0.23/0.13 (1.91)	0.41/0.31 (1.81)
Intersection 2	0.29/0.25 (0.57)	21.4/17.2 (3.97)	25.6/19.5 (4.15)	0.32/0.16 (2.59)	0.58/0.37 (3.84)
Intersection 3	0.34/0.23 (1.95)	20.7/17.5 (2.85)	25.2/20.1 (3.27)	0.34/0.18 (2.54)	0.6/0.37 (3.64)
Intersection 4	0.36/0.27 (0.92)	21.8/17.9 (2.87)	25.9/20.9 (2.81)	0.36/0.2 (2.48)	0.54/0.4 (1.93)
Intersection 6	0.34/0.20 (2.37)	22.6/18.0 (3.56)	27.1/21.2 (3.5)	0.36/0.22 (2.19)	0.61/0.4 (3.12)
Intersection 8	0.42/0.27 (1.48)	21.3/17.5 (3.36)	25.7/20.4 (3.47)	0.32/0.2 (2.24)	0.58/0.38 (3.10)
Intersection 9	0.25/0.25 (0.10)	22.3/17.6 (3.55)	26.2/20.7 (3.45)	0.34/0.19 (2.36)	0.52/0.38 (2.06)

Time-to-violation

Time-to-violation was calculated as the expected time to reach the intersection at the moment the signal turns red based on the subject's speed at that moment (the same as time-to-collision, but with respect to the intersection ahead rather than a leading vehicle). For the blocked intersection scenario, time-to-violation was calculated from the beginning of the first red phase, which is before the occurrence of the scenario.

As shown in Table V, males and older drivers had higher values of time-to-violation compared to females and younger drivers. However, these differences were not significant at the 95% level of confidence. Significant differences were however observed between violators and non-violators, as violators had significantly lower time-to-violation values at all intersections at the 90% level of confidence, and at 4 out of 7 intersections at the 95% level of confidence.

Time-to-violation can be an important predictor of violations. The average time-to-violation before the 28 violation events was 3.6 seconds, while that before non-violation events was

5.1 seconds. The difference was significant at the 95% level of confidence, where the t-statistic had a value of 6.2.

Table V – Differences in time-to-violation (seconds) at each intersection

Intersection Number	Females/Males (t-stat)	Younger Drivers/ Older Drivers (t-stat)	Violators/ Non-Violators (t-stat)
Intersection 1	5.52/5.94 (1.08)	5.61/6.11 (1.65)	5.15/6.06 (2.97)
Intersection 2	4.72/4.83 (0.27)	4.64/4.98 (1.08)	4.26/4.97 (1.78)
Intersection 3	5.12/4.83 (0.65)	4.82/5.00 (0.54)	4.37/5.07 (1.76)
Intersection 4	4.16/4.73 (1.59)	4.41/4.81 (1.32)	3.77/4.85 (3.15)
Intersection 6	4.75/5.28 (1.17)	5.01/5.32 (0.82)	4.58/5.33 (1.64)
Intersection 8	4.18/4.67 (1.67)	4.31/4.82 (1.74)	3.93/4.74 (3.11)
Intersection 9	5.07/5.24 (0.34)	5.05/5.37 (0.88)	4.42/5.44 (2.40)

Honking

The honk was used by 56 subjects (69% of the sample). As indicated in Table VI below, males were more likely to use the honk compared to females, which is in accordance with the results reported by Doob and Gross (1968). Similarly, younger subjects used the honk more than older subjects, and violators used the honk more than non-violators.

Table VI – Honking

Group	Honk Usage (%)
Violators	79%
Non-Violators	66%
Young Drivers (18-19)	74%
Older Drivers (20+)	63%
Males	73%
Females	58%

The honk was mostly used at the blocked intersections scenario (53 individuals). However some subjects also honked at violating vehicles while they were waiting at a red signal (6 individuals). Honking was not observed at the short green scenario; however one individual used the honk at the second control intersection. This might be explained by Shinar's (1998) claim regarding hostile aggressiveness, whereby using the horn makes the driver feel better without improving the situation.

Self-reported aggressiveness

The survey responses for different groups (genders, age groups, and violators/non-violators) were analyzed. The average responses for males were higher for 22 statements out of 33. However, the differences were significant at the 90% level of confidence for 6 statements only, while females had significantly higher responses for two statements. As shown in Table VII, males reported higher confidence in driving compared to females and higher hostile aggressions such as verbal insults, rude gestures, and flashing headlights. Females however reported higher irritation and driving dislike compared to males. However, these statements do not represent violations or risky vehicle maneuvers, but rather driving attitudes and offensive behavior towards other drivers.

Table VII – Significant differences in survey responses between males and females

Question	Average Response on a scale of 1 (strongly disagree) – 5 (strongly agree) (Females/Males (t-stat))
I am a confident driver.	3.95/4.38 (1.86)
I believe I have enough experience and training to deal with risky situations on the road safely.	3.53/3.90 (1.82)
Driving brings out the worst in people.	4.00/3.16 (3.96)
I flash my headlights when I am annoyed by another driver.	2.47/3.30 (2.60)
I make rude or inappropriate gestures towards drivers who annoy me.	1.42/1.97 (2.68)
I verbally insult drivers who annoy me.	1.44/1.82 (1.79)
I race other drivers at traffic lights to get ahead once lights turn green.	1.63/2.35 (2.28)
When I get stuck in a traffic jam I get very irritated.	3.89/3.43 (1.88)

Similarly, only four survey responses had significant differences at the 90% level of confidence between age groups. As shown in Table VIII, older drivers (aged 20 or more) reported significantly higher self confidence in driving compared to younger drivers (18-19 years old), while younger drivers reported higher irritation (losing one's temper) while driving or being stuck in traffic. These statements also represent attitudes towards driving only.

Table VIII – Significant differences in survey responses between age groups

Question	Average Response on a scale of 1 (strongly disagree) – 5 (strongly agree) (Younger drivers/Older drivers (t-stat))
I am a confident driver.	4.42/4.14 (1.86)
I believe I have enough experience and training to deal with risky situations on the road safely.	4.03/3.63 (2.14)
I lose my temper while driving.	2.42/2.98 (2.63)
When I get stuck in a traffic jam I get very irritated.	3.29/3.74 (1.90)

The average responses of violators were higher than those of non-violators for 30 statements out of 33 (subjects who violated at least one red light in the simulator experiment). Out of these, 12 responses were significant at the 90% level of confidence. As shown in Table IX, violators reported higher answers for questions focusing on violations, speeding, and striking back at other drivers who annoy them. The results indicate that red-light violators also engage in other violations and act aggressively towards other drivers. These statements did not only represent attitudes towards driving but also risky maneuvers and violations.

Table IX – Significant differences in survey responses between violators and non-violators

Question	Average Response on a scale of 1 (strongly disagree) – 5 (strongly agree) (Violators/Non-Violators (t-stat))
I feel that most traffic "laws" could be considered as suggestions.	2.53/1.94 (2.30)
I tend to disregard traffic laws when I see others disregarding them.	2.68/1.76 (3.22)
I intentionally disregard the speed limit.	2.84/2.18 (2.26)
I intentionally cross a red light.	2.16/1.46 (3.18)
I drive even when I am angry or upset.	3.89/3.38 (2.09)
I flash my headlights when I am annoyed by another driver.	3.53/2.97 (1.66)
I deliberately use my car to block drivers who tailgate me (follow me closely).	2.37/1.71 (2.06)
I would tailgate a driver who annoys me.	2.11/1.63 (1.73)
I race other drivers at traffic lights to get ahead once lights turn green.	2.84/1.98 (2.38)
I will illegally pass a car/truck that is going too slowly.	3.74/2.49 (4.09)
Passengers in my car/truck tell me to calm down.	2.53/1.94 (2.51)
I will drive in the shoulder lane or median (extreme right or left) to get around a traffic jam.	3.11/2.54 (2.09)

A total of 1155 correlations between survey responses and the post-intersection measures (maximum and average speed, maximum and average pedal depression, and standard deviation in lateral position) were computed. Out of these, 999 were positive correlations. At the 90% level of confidence, 504 of the 999 positive correlations were significant, compared to 380 significant positive correlations at the 95% level of confidence. These results indicate that individuals with higher self-reported aggressiveness are more likely to engage in aggressive driving behavior. The most positive and significant correlations were related to statements focusing on risk taking, speeding, violations, and illegal maneuvers. All of these statements represent the “instrumental aggressiveness” defined before. On the other hand, the mildest correlations were related to statements focusing on “hostile aggressiveness” such as making rude gestures and verbal insults and on driving dislike and irritation. These results indicate that “hostile” aggressors are not necessarily instrumental aggressors, and vice versa.

Most of the positive correlations were found between survey responses and speeding (224 positive correlations out of 231 for average speed and 227 out of 231 for maximum speed), and pedal depression (216 positive correlations out of 231 for average pedal depression and 221 out of 231 for maximum pedal depression).

CONCLUSION

This study examined the relationship between aggressive driving behavior at intersections and the occurrence of frustrating events, such as short green phases, vehicles blocking the intersection in the perpendicular direction, and signal violations committed by other vehicles. In addition, the effects of gender, age, and self-reported driving aggressiveness were studied. The number of red light violations, speed profiles, gas pedal depression, time-to-violation, and honk usage were analyzed as indicators of aggressive driving.

The results indicated that the three frustrating events mentioned above encourage violations at intersections, and cause drivers to engage in risky driving behavior after crossing the intersection. However, gender and age did not have a significant effect on the number of violations or other measures except for honk usage, whereby males and younger drivers used the honk more than females and older drivers.

Significant differences were only observed between violators and non-violators for speed, pedal depression, and time-to-violation. In addition, violators demonstrated more honk usage compared to non-violators.

The results also indicated that the occurrence of several frustrating events causes driving aggressiveness to increase incrementally. This was confirmed by comparing the number of violations and other measures (speed, pedal depression, and lateral deviation) at the three control intersections (first, sixth, and ninth intersections).

Survey responses were consistent with the observed driving behavior in the simulator. It was also inferred that red-light violators are also likely to commit other driving violations and engage in instrumental aggressive behavior.

This research has several policy implications on the signal timing, warning signs, and enforcement. Short green phases must be avoided when possible. Warning signs must be used in order to ensure that drivers will not block the intersection if they cannot completely cross it, and fines may be charged to violators. Finally, strict enforcement should be applied because drivers can be provoked when they see others violating traffic laws, which causes them to violate them too.

This study presented some important insights about aggressive driving behavior at signalized intersections and its manifestations. However, driving simulation might not be identical to real life driving since subjects do not experience the sense of risk, urgency, or time pressure as they do in real driving. Moreover, self-selection might be an important bias since the experiment is voluntary; those who choose to participate may have a different driving behavior compared to those who do not participate. In future research, the attitudinal survey that was administered to the study participants can also be administered to a sample of non-participants to test whether the driving aggressiveness tendencies of participants and non-participants differ significantly.

Future research should also focus more on the quantitative aspects associated with the events encountered in the simulation, such as the total waiting time at the intersection and the minimum acceptable length of a green phase. It can also examine other factors affecting aggressive driving behavior, such as time pressure and congestion. The sample should also be extended to include typical drivers, and not only university students. Finally, choice models can be developed to predict the probability of violating red lights as a function of the aggressiveness induced by these events and socio-demographic characteristics of drivers.

REFERENCES

Baron, R. A. and D. Byrne (1994). Social Psychology (7th ed.). Boston: Allyn and Bacon.

Beittany, N., B. N. Campbell, J. D. Smith and W. G. Najm (2004). Analysis of fatal crashes due to signal and stop sign violations. (Report No. DOT HS-809-779). Washington, DC: National Highway Traffic Safety Administration.

Blaauw, G.J. (1982). Driving experience and task demands in simulator and instrumented car: a validation study. Human factors, 24, 473-486.

Deffenbacher, J. L., D. M. Deffenbacher, R. S. Lynch T. L. and Richards (2003). Anger, aggression, and risky behaviour: A comparison of high and low anger drivers. Behaviour Research and Therapy, 41, 701–18.

Deffenbacher, J. L., M. E. Huff, R. S. Lynch, E. R. Oetting and N. F. Salvatore (2000). Characteristics and treatment of high-anger drivers. Journal of Counseling Psychology, 47, 5−17.

Doob, A. N. and A. E. Gross (1968). Status of frustrator as an inhibitor of horn-honking responses. Journal of Social Psychology, 76, 213-218.

Dula, C. S. and M. E. Ballard (2003). Development and evaluation of a measure of dangerous, aggressive, negative emotional, and risky driving. Journal of Applied Social Psychology, 33 (2), 263–282.

Ellison-Potter, P., P. Bell and J. L. Deffenbacher (2001). The effects of trait driving anger, anonymity, and aggressive stimuli on aggressive behavior. Journal of Applied Social Psychology, 31, 431-443.

Fisher, D., M. Rizzo, J. Caird and J. Lee (2011). Simulator validity: behaviors observed on the simulator and on the road. Handbook of Driving Simulation For Engineering, Medicing, and Psychology, Chapter 13.

Hamdar, S. H., H. S. Mahmassani and R. B. Chen (2008). Aggressiveness propensity index for driving behavior at signalized intersections. Accident Analysis and Prevention, 40, 315-326.

Hoskins, A. and M.El-Gindy (2006). Technical report: Literature survey on driving simulator validation studies. International Journal of Heavy Vehicle Systems. 13, 3.

Kaysi, I. A. and A. S. Abbany (2007). Modeling aggressive driver behavior at unsignalized intersections. Accident Analysis and Prevention, 39, 671-678.

Lajunen, T. and D. Parker (2001). Are aggressive people aggressive drivers? A study of the relationship between self-reported general aggressiveness, driver anger and aggressive driving. Accident Analysis and Prevention, 33 (2), 242–255.

Lee Y.C. (2010). Measuring Drivers' Frustration in a Driving Simulator. 54th Human Factors and Ergonomics Society Annual Meeting. San Francisco, CA.

Martinez, R. (1997). Testimony to House Transportation and Infrastructure Committee. Surface Transportation Subcommittee (Retrieved June 30, 1998, from the World Wide Web: http://www.nhtsa.dot.gov/nhtsa/announce/testimony/aggres2.html).

Matthews, G., L. Dorn, T. W. Hoyes, D. R. Davies, A. I. Glendon, and R. G. Taylor (1998). Driver stress and performance on a driving simulator. Human Factors, 40, 136−149.

Matthews, G., P. A. Desmond, L. Joyner, B. Carcary and K. Gilliland (1997). A comprehensive questionnaire measure of driver stress and affect. In: Traffic and Transport Psychology: Theory and Application (T. Rothengatter and E. C. Vaya), pp. 317-324, Pergamon, Amsterdam.

Nesbit, S. M., J. C. Conger and A. J. Conger (2007). A quantitative review of the relationship between anger and aggressive driving. Aggression and Violent Behavior: A Review Journal, 12, 156-176.

Philippe, F. L., R. J. Vallerand, I. Richer, E. Vallières and J. Bergeron (2009). Passion for driving and aggressive driving behavior: A look at their relationship, Journal of Applied Social Psychology, 39, 12, 3020-3043.

Porter, B.E. (1999). A nationwide survey of red light running: measuring driver behaviors for the "stop red light running" program. Research Foundation: 57, Old Dominion University, Norfolk, Virginia.

Reason, J., A. Manstead, S. Stradling, J. Baxter and K. Campbell (1990). Errors and violations: a real distinction? Ergonomics, 33, 1315-1332.

Shinar, D. (1998). Aggressive driving: the contribution of the drivers and the situation. Transport Research Part F, 1, 137–160.

Spielberger, C. D. (1988). State-trait anger expression inventory: Professional manual. Odessa, FL: Psychological Assessment Resources.

APPENDIX A: SURVEY QUESTIONS

Table X – Section 1 of the survey

Section 1: Answers on a scale of 1 to 5 (Strongly disagree – Strongly agree)
1. I am a confident driver.
2. I believe I have enough experience and training to deal with risky situations on the road safely.
3. I get a real thrill out of driving fast.
4. I enjoy the sensation of accelerating rapidly.
5. I consider myself to be a risk-taker.
6. I like to raise my adrenaline levels while driving.
7. I feel that most traffic "laws" could be considered as suggestions.
8. Driving brings out the worst in people.
9. I feel it is my right to get where I need to go as quickly as possible.
10. I consider the actions of other drivers to be inappropriate or "stupid".
11. I feel it is my right to strike back in some way, if I feel another driver has been aggressive toward me.

12. I feel that passive drivers (who are slow to react) should learn how to drive or stay home.
13. I tend to disregard traffic laws when I see others disregarding them.

Table XI – Section 2 of the survey

Section 2: Answers on a scale of 1 to 5 (Never – Always)
14. I exceed the speed limit without realizing it.
15. I intentionally disregard the speed limit.
16. I intentionally cross a red light.
17. I drive even when I am angry or upset.
18. I lose my temper while driving.
19. I flash my headlights when I am annoyed by another driver.
20. I honk the horn when I am annoyed by another driver.
21. I make rude or inappropriate gestures towards drivers who annoy me.
22. I verbally insult drivers who annoy me.
23. I deliberately use my car to block drivers who tailgate me (follow me closely).
24. I would tailgate a driver who annoys me.
25. I race other drivers at traffic lights to get ahead once lights turn green.
26. I will illegally pass a car/truck that is going too slowly.
27. When I get stuck in a traffic jam I get very irritated.
28. I will weave (move from lane to lane) to avoid slower traffic.
29. When someone cuts me off (changes lane in front of me abruptly), I feel I should punish him/her.
30. I get impatient and/or upset when I fall behind schedule when I am driving.
31. Passengers in my car/truck tell me to calm down.
32. I get irritated when a car/truck in front of me slows down for no reason.
33. I will drive in the shoulder lane or median (extreme right or left) to get around a traffic jam.