MEASURING AGGRESSIVE DRIVING BEHAVIOR USING A DRIVING SIMULATOR: AN EXPLORATORY STUDY

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ABSTRACT

Aggressive driving is typically stimulated by impatience, frustration, or anger and manifests itself through unsafe driving behaviors such as running red lights, traffic weaving, or tailgating. Studying aggressive driving behavior is important since such behavior has been shown to be a major cause of traffic accidents and quantifying it and its determinants can help design programs that aim at reducing aggressive driving behavior. This paper studies aggressive driving behavior of university students by using a driving simulator to generate certain events in the traffic environment and evaluate drivers' reactions to those events. The study aims at testing two hypotheses. The first hypothesis is that a series of frustrating events in the driving environment may instigate drivers to drive aggressively even if they may be non-aggressive by nature. The second hypothesis is that the level of trait aggressiveness influences the extent to which drivers react aggressively to frustrating events in the traffic environment. To test these hypotheses, an experimental procedure is used whereby a sample of student subjects at the American University of Beirut are recruited to drive through traffic scenarios represented in the driving simulator and aiming at instigating the subjects' aggressiveness. Overall, the results indicate that there is evidence to support both hypotheses.

Keywords: aggressive driving, driving simulator, instigation of aggressiveness, traffic safety.

1. INTRODUCTION

Aggressive driving is manifested through a combination of willful traffic offenses or unsafe driving behaviors such as running red lights, traffic weaving, tailgating, or "forced" merging (National Highway Traffic Safety Administration; Neuman et al., 2003; Tasca, 2000). It is seen as any driving behavior stimulated by impatience/time pressure, frustration, or anger that psychologically and physically endangers others (see, for example, Shinar, 1998). A distinction can be made between state and trait aggressiveness. State aggressiveness refers to aggressive behavior that is provoked by events such as traffic conditions (e.g. congestion, length of red light interval, etc.) or behavior of other drivers (such as honking and tailgating). Trait aggressiveness refers to aggressive driving behavior that results from a driver who is aggressive by nature.

Studying aggressive driving behavior is important for a number of reasons. First, from a safety point of view, aggressiveness has been shown to be a major cause of traffic accidents (AAA Foundation for Traffic Safety, 2009). Quantifying aggressive driving behavior, its determinants, and its contribution to traffic accidents can help design programs that aim at reducing aggressive driving behavior (ranging from traffic enforcement, to education, and to engineering solutions such as better coordinating traffic signals, lowering speed limits, or providing information to drivers about the causes of traffic delay). Second, a better understanding of aggressive driving behavior can lead to more behaviorally realistic representations of traffic in microsimulator models, which are essential components of the evaluation of Intelligent Transportation System strategies. The core of these microsimulators is driving behavior models that move individual vehicles according to lane changing, gap acceptance, and car-following models, and these driving maneuvers are likely to be affected by aggressiveness levels (e.g. more lane changes, shorter gaps accepted for lane changes, and following other cars more closely).

This paper studies aggressive driving behavior of university students by using a driving simulator to generate certain events in the traffic environment and evaluate drivers' reactions to those events. The study specifically aims at testing two hypotheses. The first hypothesis is that a series of frustrating events in the driving environment, related to other drivers' behavior or to general traffic conditions and control, may instigate drivers to drive aggressively even if they may be non-aggressive by nature. This hypothesis may be supported by the frustration-aggression model (Dollard et al., 1939) which links frustration to subsequent instigation to some form of aggression as a possible reaction. The second hypothesis is that the level of trait aggressiveness influences the extent to which drivers react aggressively to frustrating events in the traffic environment. That is, people who have an aggressive personality or attitudes towards driving are more likely to exhibit these aggressive tendencies in driving. While this may be an obvious assertion to make, this study aims to test the extent to which this aggression is manifested under different conditions. While other studies reviewed in Section 2 have found a correlation between self-reported passion for driving or level of hostility and driving performance in a simulator, the present study investigates this correlation using a different measure of self-reported trait aggressiveness.

To test these hypotheses, an experimental procedure is used whereby a sample of student subjects at the American University of Beirut (AUB) are recruited to drive through three traffic scenarios represented in the simulator and aiming at instigating the subjects' aggressiveness. The events generated in these scenarios involve driving behind a slow bus with limited passing

opportunities, arriving on yellow at signalized intersections, and making a left turn amid heavy opposing traffic and aggressive tailgating vehicles. The availability of driving performance data from the simulator (detailed trajectories and other scenario-specific measures) and subjects' characteristics from a survey (personality and attitudes towards driving) enabled the quantification of the extent of aggressive driving and its relationship to trait aggressiveness.

This research tests new methods for measuring and studying aggressive driving behavior using a driving simulator. In this regard, the theoretical merit of the research lies in the eventual development of richer driving behavior models which capitalize on the availability of multiple types of driver-related data (attitudes and driving performance). The practical implications lie in a better understanding of the nature of events that trigger aggressive driving behavior, which could hopefully be of value to the design of safety programs or regulations aiming at reducing aggressiveness in driving.

The remainder of this paper is organized as follows. Section 2 reviews some of the more recent studies 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 recruitment procedure and the sample. Section 6 presents the analysis of the data. Section 7 concludes the paper.

2. LITERATURE REVIEW

This section reviews a number of recent studies on driving aggressiveness based on field observations, surveys, and driving simulators.

2.1 Studies Based on Field Observations

Field studies have the advantage of capturing realistic driving behavior but often lack data about the drivers. An overview of a number of these studies focusing specifically on modeling driving behavior follows.

Kaysi and Abbany (2007) modeled aggressive driving behavior at unsignalized intersections in Beirut. They observed gap acceptance and merging at U-turns and developed a probit model that predicts the probability that a driver merges in an aggressive manner. Their classification of aggressive driving behavior was based on the observation of whether the merging driver forced himself in the main traffic or not. They found that age, car performance, and average speed of the major traffic were important predictors of aggressive merging maneuvers. Choudhury (2007) estimated models of freeway lane changing using disaggregate trajectory data without driver-related data. Driving aggressiveness was modeled as a random variable and included in a target lane choice model. The estimation results indicated that compared to timid drivers, aggressive drivers are less likely to choose the right lane over the left lane. Hamdar et al. (2008) developed a propensity index for aggressive driving behavior at signalized intersections with the aim of determining the factors that make certain intersections more prone to aggressive driving behavior. They conceptualized aggressive driving behavior as being manifested through start-up delay when the signal indication turns green, acceleration when the signal indication turns yellow, gap acceptance, and lane changing. In an application to signalized intersections in Washington DC, and using structural equation modeling, they found that a number of factors

contribute to aggressive driving, including the surrounding moving traffic and pedestrians, the intersection geometry, the red timing, and the presence of law enforcement figures. Paleti et al. (2010) modeled the effect of a number of variables on injury severity in traffic crashes through the moderating effect of aggressiveness. Using a US database of crashes, their measure of aggressiveness was based on the determination of a group of trained researchers who classified a crash as involving aggressive behavior or not. Using structural equation modeling, they found that a number of factors affect driving aggressiveness, including driver characteristics (such as gender, age, seat belt usage, etc.), environmental and situational factors (such as time of day, weather, and company in the car), vehicle characteristics (such as type of vehicle), and roadway characteristics (such as speed limit). They also found that aggressiveness impacted the severity of injuries in crashes.

2.2 Studies Based on Surveys

Studies based on surveys rely on self-reported measures of aggressiveness as opposed to inferences based on actual driving. Within this class of studies, a number of questionnaires have been developed to measure driving aggressiveness, including the driving anger scale (Deffenbacher et al., 1994) whereby respondents rate the degree of anger they would experience if faced with certain driving situations; the aggression questionnaire (Buss and Perry, 1992) whereby respondents rate several statements that measure to what extent they are aggressive (in general) by nature; and other questionnaires that measure aggressive driving attitudes and the self-reported frequency of certain aggressive driving behaviors (Miles and Johnson, 2003). Other studies have examined the extent to which driving aggressiveness is a trait (Lajunen and Parker, 2001), or the extent to which self-reported driving aggressiveness is a predictor of self-reported car crashes (Chliaoutakis et al., 2002).

2.3 Studies Using Driving Simulators

Studies using driving simulators allow observations of driving behavior as well as measurement of drivers' characteristics through surveys. Even though the representation of driving behavior in simulators is less realistic than that measured in the field, they allow greater experimental control and simpler data collection procedures. As a result, a number of transportation studies have utilized driving simulators, including studies of fatigue and distraction and more generally human factors research (Mehler et al., 2009; Reimer et al., 2006), safety and traffic accidents (Fiorentino and Parseghian, 1997; Lee et al., 2002, 2003), traffic engineering studies (Klee and Radwan, 2005), and gap acceptance studies (Alexander et al., 2002; Farah et al., 2009; Yan et al., 2003).

The study of driving aggressiveness using driving simulators has been more limited. Al-Shihabi and Mourant (2003) presented a conceptual framework for making the driving patterns of autonomous vehicles within a simulator more realistic; they implemented models in the simulator that can represent various types of driving behavior, including aggressive driving. Along the same lines, in Cai et al. (2007), subjects driving a simulator were subjected to aggressive driving by surrounding vehicles (e.g. flashing headlights, weaving in and out of traffic, etc.), and their driving performance and physiological reactions were recorded. Harder et al. (2008) classified research subjects by their level of self-reported hostility, and then compared

the driving performance of subjects by hostility level and gender as a reaction to various events in a driving simulator. The events were blocking of the subject's path by two vehicles moving slowly ahead of the subject, cutting off in front of the subject vehicle, and tailgating the subject vehicle. Their main findings were that compared to subjects in the low hostility group, subjects in the high hostility group kept a significantly smaller distance to the vehicles moving slowly ahead and started braking sooner when they were cut off by another vehicle. Philippe et al. (2009) examined the relationship between "obsessive" passion for driving and aggressive driving behavior using a driving simulator. They used both self-reported measures of aggressive driving behavior and observed measures based on judges' evaluations of the reactions of the subjects undergoing the simulator experiments. They found correlations between obsessive passion for driving and aggressive driving behavior when subjects are instigated to drive aggressively in the simulator, as well as a mediating effect of anger in the passion-aggressiveness relationship.

Our paper extends this stream of studies by analyzing drivers' reactions to situations instigating their aggressiveness and correlating their driving behavior to their self-reported trait aggressiveness.

3. DRIVING SIMULATOR DESCRIPTION

The driving simulator that is used in this research is a DriveSafety DS-600c Research Simulator recently acquired by AUB and housed at a laboratory in the Civil and Environmental Engineering department. It consists of a full-width Ford Focus automobile cab with standard driver controls and instrumentation and some motion cues. A computer graphic of the physical road network and the traffic scenario is projected onto a 180° display screen, which allows for an immersive driving experience. A number of scenarios can be designed involving different combinations of the following elements: roads, vehicles, intersections, landscapes, traffic signals, and specific traffic events and behaviors (e.g. vehicle pulling out, etc.). The driving simulator is shown in Figure 1.

The following variables are recorded during the simulation and are available for analysis after the simulation is over: the trajectory of the subject (simulated) vehicle including position, steering, braking, velocity, and acceleration throughout the duration of the simulation, and the trajectory of other vehicles in the traffic stream. The number and speed of these vehicles can be controlled in the set-up of the scenario. Moreover, certain vehicles can be programmed to appear at certain times or locations that are tied to the trajectory of the subject vehicle (e.g. another vehicle makes a turn at an intersection when the subject vehicle is 5 seconds away from the intersection).

Figure 1 Driving simulator

4. EXPERIMENT DESIGN

The experiment consists of three phases; an introductory phase that includes a screening interview, a second phase that comprises the driving simulator experiment, and a third and final phase that involves a post-driving survey.

4.1 Phase One – Introduction and Screening Interview

The first phase introduces the subject to the research context he/she is participating in including the broad research objectives, the potential risks, the benefits, and the importance of the study confidentiality. However, and in order to reduce any possible bias, the subject is not informed that the driving experiments are meant to instigate and observe aggressive driving behavior. A consent form for participation is signed by the investigator and the participant. This is followed by a screening interview with the participant to make sure he/she is eligible to participate in the experiment and does not have any physical problems such as dizziness, sleep deprivation, eye or ear problems, etc. or psychiatric disorders or Alzheimer's disease.

4.2 Phase Two – Driving Simulator Experiment

In the second phase, the driving simulator experiment is executed whereby each subject is asked to perform first a practice run in the simulator where he/she gets introduced to the simulator and the route to be followed with light to medium traffic, and then a data collection run, where he/she is asked to follow the same route, but this time with three different traffic scenarios that are expected to trigger aggressiveness. Subjects were instructed to drive normally as they do in real life.

In the first traffic scenario shown in Figure 2, the subject gets stuck behind a school bus moving at a very low velocity (10 mi/h or 16 km/h) in a narrow two-lane urban road. The opposite traffic is designed in such a way that makes the passing maneuver almost impossible since the gaps between successive vehicles in the opposing traffic are very short and constant at 5 seconds. The subject thus is forced to follow the bus for a distance approximately equal to 320 meters. This scenario is intended to trigger the subject's anger and impatience, and possibly instigate aggressive driving behavior. The driving simulator enables the collection of several data items that describe the manner in which the subject drives behind the bus; such data is then assessed for possible indication of aggressiveness. In this scenario the following measures were considered to be the most indicative of such behavior: the maximum and standard deviation of velocity of the subject, the maximum acceleration and deceleration, the minimum and average distance of the subject from the bus, and the maximum lane position of the subject (how far the subject drifts away from the lane centerline in an attempt to pass the bus from the left side).

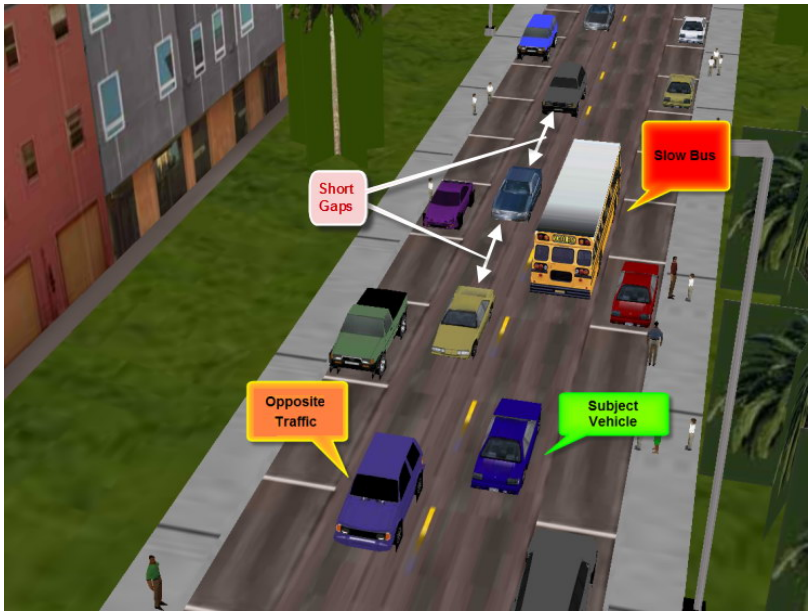

Figure 2 First traffic scenario

In the second traffic scenario shown in Figure 3 below, the subject needs to pass through two consecutive, signalized intersections, where each signal turns yellow as he/she approaches it. The intersections are totally clear of any traffic. In this scenario, the data collected by the simulator indicates whether the subject stopped at the intersection after observing the yellow light or he/she accelerated, and if so, what was the maximum acceleration reached. These two measures (stopping and maximum acceleration) are used as indicators of aggressiveness in this scenario.

Figure 3 Second traffic scenario

In the third traffic scenario shown in Figure 4, the subject has to perform a left turn, forcing himself/herself through traffic moving in the opposite direction in a narrow two-lane road. The opposite traffic has constant short gaps (about 3 seconds) and does not stop unless the subject's vehicle blocks their path (forced crossing). If the subject waits without passing for about 12 seconds, another vehicle would approach him/her from the back and start beeping and flashing headlights, thus possibly instigating the subject's aggressiveness and leading him/her to perform the forced crossing to complete the left turn. In this scenario, the simulator keeps track of the number of gaps that the driver decided to wait for before merging, and the minimum distance between the driver and the following vehicle upon crossing (it is considered that upon completing the left turn, a small distance between the subject and the vehicle behind would indicate that the subject was coerced to cross by the vehicle behind him/her).

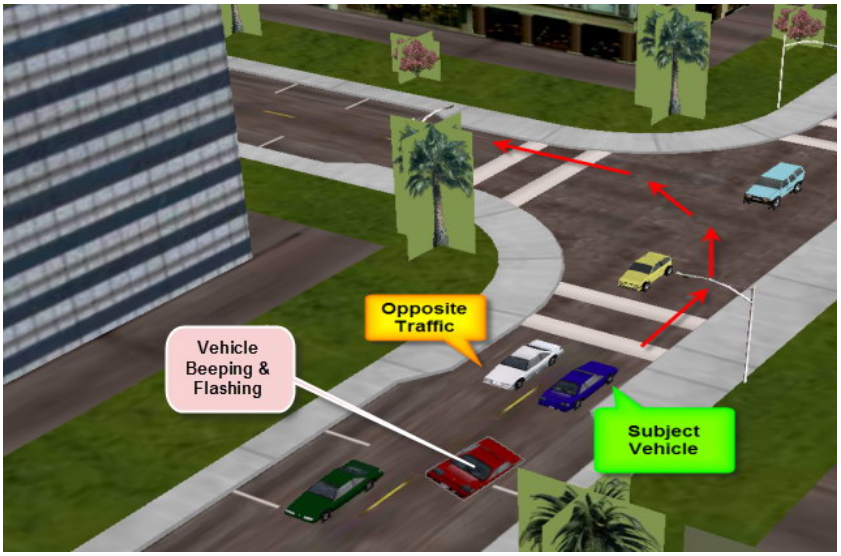

Figure 4 Third traffic scenario

A schematic of the 2.76-km trajectory followed by the subjects is presented in Figure 5. Auditory messages were used and visual signs were placed along the route to remind subjects of the trajectory they need to take.

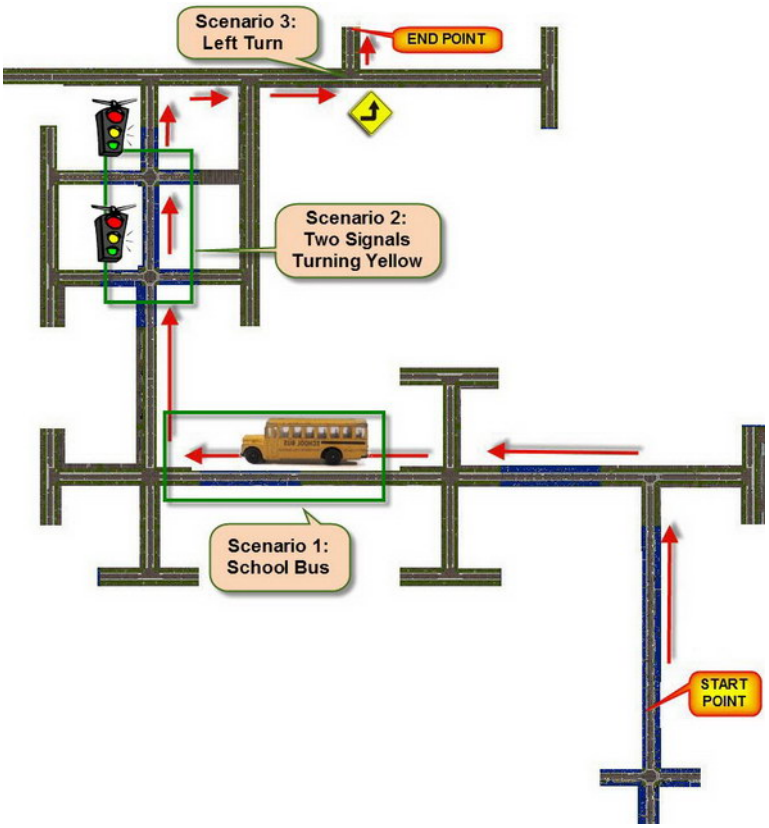

Figure 5 Driving simulator trajectory

4.3 Phase Three – Post-Driving Survey

In the third and final phase of the study, following the driving simulator experiment, each subject filled out a survey consisting of a list of questions aiming at collecting self-reported information about trait and state aggressiveness as well as previous experiences of aggressive driving. The questions are statements that subjects rated on a scale of 1 to 5 to respectively designate non-aggressive behavior up to very aggressive behavior.

Self-reported trait aggressiveness was assessed based on personality and attitudinal/behavioral pattern statements. The personality statements were rated on a scale of 1 to 5 ranging respectively from “extremely uncharacteristic of me” to “extremely characteristic of me” and consisted of the following statements taken from the aggression questionnaire (Buss and Perry, 1992):

- I tell my friends openly when I disagree with them.
- I often find myself disagreeing with people.
- When frustrated, I let my irritation show.
- I have trouble controlling my temper.
- I get into fights a little more than the average person.

The attitudinal/behavioral pattern statements were rated on a scale of 1 to 5 ranging respectively from "strongly disagree" to "strongly agree" and consisted of the following statements taken mostly from a study by Miles and Johnson (2003):

- There are too many road rules.
- Police officers should arrest drivers for going too slow.
- The driver who has the most time should be the one who yields.
- People who do not work should not be on the road during rush hour.
- Driving empowers me.
- If you are not driving fast, you do not have an important place to go.
- I possess superior driving skills.
- I generally feel impatient with the pace of traffic.
- As a passenger, I often feel the need to tell the driver what to do.
- It seems as if I'm always in the slow lane.
- The longer the driving time is for a single trip, the more aggressively I drive.

The classification of subjects into aggressive or timid based on these statements is described in Section 6.

5. RECRUITMENT AND SAMPLE DESCRIPTION

Data collection for the experiment was based on a self-selected sample of AUB students since the population of interest in this study was university students. Subjects were either approached personally by the research assistants working on this study, or volunteered themselves for participating in the study after seeing flyers distributed across campus to solicit participation. Eligibility conditions for participating in the study entailed having a driving license, not having stopped driving for more than three years, not suffering from any medical condition that could put the subject at risk while performing the experiment (as mentioned previously), and not being pregnant.

A total of 51 subjects participated in the study. Five of these subjects got extremely dizzy after performing the training run in the simulator and could not continue with the actual experiment. Four subjects were considered as outliers (e.g. driving on the curb for a long distance, making extreme turning maneuvers, traveling at a very high speed, or not taking the experiment seriously) and removed from the analysis. Therefore, the final sample used in the analysis consists of 42 student subjects. A subject's participation in the experiment (including all phases) took about 20-25 minutes. The time to complete the actual drive ranged from 4.2 to 7.6 minutes per subject, with an average of 5.5 minutes.

The sample consisted of 31 males and 11 females. The age of the subjects ranged from 18 to 25 years with an average of 21 years. Most of the subjects (37 out of 42) were students of the Faculty of Engineering and Architecture. The majority have not obtained any tickets for moving

violations since they started driving[1] (26 out of 42 subjects) and have not been involved in major accidents[2] (23 out of 42 subjects). The majority of subjects drive for more than one hour on a daily basis (16 subjects drive 1-2 hours, 15 subjects drive 2-3 hours, and 2 subjects drive more than 3 hours on a daily basis).

At the end of the experiment, and as part of the post-driving survey, the majority of subjects reported that driving in the simulator felt like real world driving, the driving speed in the simulator felt somewhat realistic, and that they felt a little dizzy while driving the simulator.

6. DATA ANALYSIS

This section presents the analysis of the three traffic scenarios described in Section 4. Subjects are first classified as aggressive or timid based on self-reported trait aggressiveness from the survey. For each scenario in the experiment, a comparison of the driving performance of aggressive and timid drivers is presented to determine the extent to which trait aggressiveness contributes to aggressive driving behavior. Some of the results shown also shed some light on the impact of factors instigating aggressiveness on driving behavior.

6.1 Classification of Subjects

As described in Section 4, subjects rated a number of personality statements on a scale of 1 to 5 where 1 represents “extremely uncharacteristic of me” and 5 represents “extremely characteristic of me”, and a set of attitudinal/behavioral pattern statements on a scale of 1 to 5 where 1 represents “strongly disagree” and 5 represents “strongly agree”. For every subject, an average rating was computed for the personality statements and another average was computed for the attitudinal/behavioral pattern statements. A trait aggressiveness score was estimated as the average of these two averages. As a higher value of the score indicates greater aggressiveness, subjects that had a score of less than or equal to 3.0 were classified as timid, and those with a score that was greater than 3.0 were classified as aggressive. Using this rule, 25 subjects were classified as timid and the remaining 17 subjects were classified as aggressive.

6.2 Scenario 1

It was hypothesized that while following the school bus in Scenario 1, and compared to timid drivers, aggressive drivers would reach a higher velocity and exhibit greater variability in velocity, apply higher acceleration/deceleration rates, follow the bus more closely, and deviate more from the centerline of the lane in an attempt to pass the bus. Table 1 shows the average values of these measures separately for aggressive and timid drivers and the standard errors of these averages in parentheses. These measures are computed over a distance of 320 meters in a

[1] The question was phrased as follows: “Since you started driving, how many tickets have you obtained for moving violations (e.g. speeding, running a red light, etc.)?”
[2] The question was phrased as follows: “Since you started driving, how many major accidents have you been involved in?”

stretch where the subject vehicle is following the bus. For every measure, a one-sided t-test of the difference in means across the two groups of drivers is conducted (assuming unequal variance and unequal sample size). The null hypothesis is that there is no difference in the values of the means across the two groups of drivers, while the alternative hypothesis is that the mean value for the aggressive drivers is greater than that for the timid drivers (for all measures except minimum and average distance to the bus, for which it is smaller). The last three rows of the table show the value of the t-statistic, the critical value of the t distribution for a 1-sided test at a 90% level of confidence and for the corresponding degrees of freedom, and the conclusion of the t-test.

Table 1 Comparison of driving performance of aggressive and timid drivers in Scenario 1 (Top panel shows the average values of the measures across drivers and the standard errors of these averages in parentheses)

	Max. Velocity (mi/h)	Std. Dev. of Velocity (mi/h)	Max. Deceleration (mi/h/s)	Max. Acceleration (mi/h/s)	Min. Distance to Bus (m)	Avg. Distance to Bus (m)	Max. Lane Position – Left (m from centerline)
Aggressive	8.53	1.06	-3.45	3.69	1.94	5.45	0.94
	(0.77)	(0.13)	(0.27)	(0.18)	(0.48)	(0.55)	(0.28)
Timid	7.23	0.92	-3.25	3.25	2.91	6.62	0.80
	(0.59)	(0.14)	(0.39)	(0.21)	(0.41)	(0.63)	(0.26)
t-stat	1.33	0.73	-0.43	1.59	-1.54	-1.39	0.35
t-critical	1.28	1.28	1.28	1.28	1.28	1.28	1.28
Conclusion	Significant	Not significant	Not significant	Significant	Significant	Significant	Not significant

The differences between the two groups are as expected but not all differences are statistically significant. The average maximum velocity reached by aggressive drivers was about 1.3 mi/h higher than that reached by timid drivers, and the difference is significant. The velocity applied by aggressive drivers was also more variable than that of timid drivers but the difference is not significant. Aggressive drivers applied higher acceleration and deceleration rates than timid drivers, but only the difference in average maximum acceleration (about 0.44 mi/h/s) is significant. Aggressive drivers also drove more closely to the bus, with the average minimum distance between the rear bumper of the bus and the front bumper of the subject about 1 meter less than that for timid drivers, and this difference is significant. A similar conclusion is reached using the average distance to bus measure. This finding is in line with results reported in Harder et al. (2008), where subjects in the high hostility group kept a considerably shorter distance from slow moving vehicles ahead compared to subjects in the low hostility group (mean distances of 14.77 meters vs. 22.87 meters). In an attempt to pass the bus, subjects were observed deviating from the centerline of the lane, and the extent of this deviation can be used to characterize aggressiveness. It was found that aggressive drivers deviated more from the centerline of the lane

compared to timid drivers, but the difference in average maximum deviation (about 0.14 meters) was not statistically significant.

Overall, these results indicate that drivers who have a high level of self-reported trait aggressiveness exhibit more aggressive driving behavior when following the bus in Scenario 1 compared to drivers with a lower level of self-reported trait aggressiveness.

6.2 Scenario 2

Table 2 shows the number and proportion of aggressive and timid subjects that stopped on yellow at intersection 1 and at intersection 2. As expected, at both intersections the proportion of aggressive drivers stopping is smaller than that of timid drivers, but the difference (about 22%) is statistically significant at the 90% level of confidence using a 1-sided t-test only at intersection 2. Table 2 also shows the average maximum acceleration among those subjects that didn't stop at each of the intersections. The maximum acceleration is computed over a distance of about 100 meters preceding the intersections. Aggressive drivers who did not stop on yellow applied on average a higher maximum acceleration than timid drivers who did not stop, but the difference is not statistically significant. The standard errors of the proportions and average maximum acceleration are shown in parentheses.

Table 2 Comparison of driving performance of aggressive and timid drivers in Scenario 2 (Top panel shows the proportions or average values of the measures across drivers and the standard errors of these proportions/averages in parentheses)

	Intersection 1			Intersection 2		
	Number Stopping	Proportion Stopping	Max. Acc. (not stopping) (mi/h/s)	Number Stopping	Proportion Stopping	Max. Acc. (not stopping) (mi/h/s)
Aggressive	9	0.53 (0.12)	2.42 (0.74)	5	0.29 (0.11)	1.40 (0.33)
Timid	18	0.72 (0.09)	1.47 (0.63)	13	0.52 (0.10)	0.99 (0.31)
t-stat		-1.23	0.97		-1.48	0.91
t-critical		1.28	1.35		1.28	1.32
Significance		Not significant	Not significant		Significant	Not significant

Moreover, for both aggressive and timid drivers, the proportion of subjects stopping on yellow at intersection 2 is smaller than that at intersection 1. This finding may indicate that stopping at intersection 1 may have instigated some drivers to become aggressive and decide not to stop at intersection 2. The extent of this instigation can be seen by examining Tables 3 and 4, which show for the aggressive and timid groups, respectively, the number of drivers by their stopping behavior at both intersections. Among the 17 aggressive drivers, 5 drivers stopped at intersection 1 but didn't stop at intersection 2, while 1 driver didn't stop at intersection 1 but stopped at

intersection 2. Among the 25 timid drivers, 6 drivers stopped at intersection 1 but didn't stop at intersection 2, while 1 driver didn't stop at intersection 1 but stopped at intersection 2. To determine whether these patterns of stopping behavior are significantly different between intersections 1 and 2, one can conduct a McNemar test of marginal homogeneity for matched pairs categorical data (Rosner, 2006) (the null hypothesis being that the proportion of subjects who don't stop at intersection 1 is equal to the proportion of subjects who don't stop at intersection 2). Since the sample size is small, a binomial test is used instead and is shown in Table 5. By comparing the probabilities shown in the table to a p-value of 0.10, it is found that the difference in stopping behavior between intersections 1 and 2 is statistically significant at the 90% level of confidence for the timid drivers but not for the aggressive drivers, thus supporting the hypothesis that events causing instigation of aggressiveness trigger the timid drivers to become more aggressive at intersection 2 compared to intersection 1.

Table 3 Distribution of aggressive drivers by their stopping behavior at intersections 1 and 2

	Didn't stop at Int. 2	Stopped at Int. 2	Total
Didn't stop at Int. 1	7	1	8
Stopped at Int. 1	5	4	9
Total	12	5	17

Table 4 Distribution of timid drivers by their stopping behavior at intersections 1 and 2

	Didn't stop at Int. 2	Stopped at Int. 2	Total
Didn't stop at Int. 1	6	1	7
Stopped at Int. 1	6	12	18
Total	12	13	25

Table 5 Binomial test for difference in stopping behavior between intersections 1 and 2

	Aggressive	Timid
Number of drivers changing their stopping behavior between intersections 1 and 2 (Y)	6	7
Number of drivers stopping at intersection 1 but not at intersection 2 (X)	5	6
Probability that X or more out of Y drivers stop at intersection 1 but not at intersection 2 (assuming a null hypothesis of a probability of 0.5 of any given driver stopping at intersection 1 but not at intersection 2)	0.109	0.063
Conclusion about difference in stopping behavior between intersections 1 and 2 (at 90% level of confidence)	Not significant	Significant

6.3 Scenario 3

To compare the performance of aggressive and timid drivers in Scenario 3, it is hypothesized that aggressive drivers wait for a smaller number of gaps in opposing traffic before making the left

turn and are more likely to make the left turn before the "instigating" following vehicle arrives behind them. Table 6 shows for aggressive and timid drivers the average number of gaps and the average minimum distance between the rear bumper of the subject vehicle and the front bumper of the following vehicle and the standard errors of these averages in parentheses. As postulated, the average number of gaps observed before making a left turn is smaller by about 1 gap for aggressive drivers but the difference is not statistically significant at the 90% level of confidence using a 1-sided t-test. The average minimum distance to the following vehicle is greater for aggressive drivers by about 7 meters and this difference is statistically significant at the 90% level of confidence, which indicates that timid drivers are more likely to make the left turn when they are instigated by a following vehicle to force their vehicles into opposing traffic.

Table 6 Comparison of driving performance of aggressive and timid drivers in Scenario 3 (Top panel shows the average values of the measures across drivers and the standard errors of these averages in parentheses)

	Number of Gaps	Min. Distance to Following Vehicle (m)
Aggressive	2.12 (0.70)	28.02 (2.61)
Timid	3.08 (0.59)	21.26 (2.71)
t-stat	-1.05	1.80
t-critical	1.28	1.28
Conclusion	Not significant	Significant

7. CONCLUSION

This research was an exploratory study of driving aggressiveness using an experiment conducted with a number of subjects in a driving simulator to instigate aggressiveness. Measures of driving aggressiveness were collected from driving performance data collected in the simulator as well as self-reports of trait and state aggressiveness. The results of the study have been consistent with the study hypotheses. First, the study has provided some evidence that a series of frustrating events in the driving environment may instigate drivers to drive aggressively even if they may be non-aggressive by nature. This was demonstrated in particular in Scenario 2 whereby a significantly smaller number of timid drivers was found to stop at intersection 2, compared to intersection 1. Second, a number of measures in all three scenarios have provided evidence to support the second hypothesis that the level of trait aggressiveness influences the extent to which drivers react aggressively to frustrating events in the traffic environment. It was consistently demonstrated that aggressive drivers behaved differently (more aggressively) when compared to timid drivers in the three scenarios. Additional analyses comparing differences in driving behavior between males and females were inconclusive; some of the measures indicated that males drove more aggressively while others indicated that females drove more aggressively. Overall, the findings of this study are specific to the population of university students from whom the study sample was drawn.

Some of the findings are comparable to those in other studies of driving aggressiveness using a driving simulator. First, and as mentioned before, the finding that aggressive drivers kept a smaller distance to a slow moving vehicle in front has been observed by Harder et al. (2008) who compared the driving behavior of a high hostility group and a low hostility group. Second, the effect of personality on aggressive driving behavior observed in this study, whereby subjects who are more aggressive by nature tended to exhibit more aggressive driving behavior, is comparable to Philippe et al.'s (2009) finding of the presence of correlation between obsessive passion for driving and aggressive driving behavior (effect mediated by anger).

The present research extends this literature by showing that frustrating driving events can trigger people who may be non-aggressive by nature to drive aggressively (first hypothesis), and by using a different measure of self-reported aggressiveness to test the second hypothesis. It has to be recognized that, due to time limitations, the sample size used in the analysis is rather small, and future extensions of this work are planned to include larger samples which could allow testing the effect of the order of the scenarios on aggressiveness. Future extensions will also investigate different ways to classify aggressiveness based on self-reports, actual driving performance (e.g. in a base stretch with no instigating events), and physiological monitoring of drivers' states such as heart rate, skin conductance, etc., and methods to make the driving experience seem more realistic to the subjects (e.g. by instructing them to arrive at the destination by a certain time).

Nevertheless, this research has tested new approaches for studying aggressive driving behavior using a driving simulator, and the results will hopefully provide some direction for future studies on the subject. Finally, the theoretical merit of the research lies in the eventual development of richer driving behavior models which capitalize on the availability of multiple types of driver-related data (attitudes, driving performance, and physiological measurements).

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REFERENCES

AAA Foundation for Traffic Safety (2009). Aggressive driving: Research update. Washington, DC, http://www.aaafoundation.org/pdf/AggressiveDrivingResearchUpdate2009.pdf (Feb. 2011).

Alexander, J., Barham, P., and Black, I. (2002). "Factors influencing the probability of an accident at a junction: Results from an interactive driving simulator", *Accident Analysis and Prevention*, 34, 779-792.

Al-Shihabi, T. and Mourant, R. R. (2003). "Toward more realistic driving behavior models for autonomous vehicles in driving simulators", Presented at the 82nd annual meeting of the Transportation Research Board, Washington, DC.

Buss, A. H. and Perry, M. P. (1992). "The aggression questionnaire", *Journal of Personality and Social Psychology*, 63, 452-459.

Cai, H., Lin, Y., and Mourant, R. R. (2007). "Study on driver emotion in driver-vehicle-environment systems using multiple networked driving simulators", Presented at the Driving Simulation Conference, North America.

Chliaoutakis, J. E., Demakakos, P., Tzamalouka, G., Bakou, V., Koumaki, M., and Darviri, C. (2002). "Aggressive behavior while driving as a predictor of self-reported car crashes", *Journal of Safety Research*, 33, 431-443.

Choudhury, C. (2007). "*Modeling Driving Decisions with Latent Plans*", Ph.D. Dissertation, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Deffenbacher, J. L., Lynch, R. S., and Oetting, E. R. (1994). "Development of a driving anger scale", *Psychological Reports*, 74(1), 83-91.

Dollard, J., Doob, L. W., Miller, N. E., Mowrer, O. H., and Sears, R. R. (1939) "*Frustration and Aggression*", Yale University Press, New Haven, Connecticut.

Farah, H., Bekhor, S., and Polus, A. (2009). "Risk evaluation by modeling of passing behavior on two-lane rural highways", *Accident Analysis and Prevention*, 41, 887-894.

Fiorentino, D. D. and Parseghian, Z. (1997). "Time-to-Collision: a Sensitive Measure of Driver Interaction with Traffic in a Simulated Driving Task", *Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting*, Albuquerque, New Mexico.

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

Harder, K. A., Kinney, T. A., and Bloomfield, J. R. (2008). "*Psychological and Roadway Correlates of Aggressive Driving*", Final Report, Center for Human Factors Systems Research and Design, University of Minnesota.

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

Klee, H. and Radwan, E. (2005). "*Traffic Engineering Studies Using a Driving Simulator*", Year 2: Final Report, University of Central Florida. http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_TE/FDOT_BD548_02_rpt.pdf (Feb. 2011)

Lajunen, T. and Parker, D. (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, 243-255.

Lee, H. C., Lee, A. H., Cameron, D., and Li-Tsang, C. (2003). "Using a driving simulator to identify older drivers at inflated risk of motor vehicle crashes", *Journal of Safety Research*, 34, 453-459.

Lee, J. D., McGehee, D. V., Brown, T. L., and Reyes, M. L. (2002). "Collision warning timing, driver distraction, and driver response to imminent rear-end collisions in a high-fidelity driving simulator", *Human Factors*, 44(2), 314-334.

Mehler, B., Reimer, B., Coughlin, J. F., and Dusek, J. A. (2009). "Impact of incremental increases in cognitive workload on physiological arousal and performance in young adult drivers", *Transportation Research Record: Journal of the Transportation Research Board*, 2138, 6-12.

Miles, D. E. and Johnson, G. L. (2003). "Aggressive driving behaviors: Are there psychological and attitudinal predictors", *Transportation Research Part F*, 6, 147-161.

National Highway Traffic Safety Administration (no date). Aggressive driving enforcement. strategies for implementing best practices.
http://www.nhtsa.gov/people/injury/enforce/aggressdrivers/aggenforce/index.html (Feb. 2011)

Neuman, T. R., Pfefer, R., Slack, K. L., Hardy, K. K., Raub, R., Lucke, R., and Wark, R. (2003). "*Guidance for Implementation of the AASHTO Strategic Highway Safety Plan. Volume 1: A Guide for Addressing Aggressive-Driving Collisions*", NCHRP Report 500, Transportation Research Board, Washington, DC.

Paleti, R., Eluru, N., and Bhat, C. R. (2010). "Examining the influence of aggressive driving behavior on driver injury severity in traffic crashes", *Accident Analysis and Prevention*, 42, 1839-1854.

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

Reimer, B., Mehler, B., Pohlmeyer, A. E., Coughlin, J. F., and Dusek, J. A. (2006). "The use of heart rate in a driving simulator as an indicator of age-related differences in driver workload", special issue of *Advances in Transportation Studies, An International Journal*.

Rosner, B. (2006). "*Fundamentals of Biostatistics*", 6th Edition, Cengage Learning, USA.

Shinar, D. (1998). "Aggressive driving: the contribution of the drivers and the situation", *Transportation Research Part F*, 1, 137-160.

Tasca, L. (2000). "A review of the literature on aggressive driving research", Presented at Aggressive Driving Issues Conference. http://www.stopandgo.org/research/aggressive/tasca.pdf (Feb. 2011)

Yan, X., Radwan, E., and Klee, H. (2003). "Driving simulators application to left turn gap acceptance", *Simulation Series*, 35, 590-595.