Reaction times of young alcohol-impaired drivers

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Abstract

Young individuals who drive under the influence of alcohol have a higher relative risk of crash involvement; as such, the literature has extensively investigated the factors affecting such involvement through both post-accident surveys and simulator experiments. The effects of differentiated breath alcohol concentrations (BrAC) on young driver behavior, however, have been largely unaddressed, mainly as a result of the difficulty in collecting the necessary data. We explore young driver behavior under the influence of alcohol using a driving simulator experiment where 49 participants were subjected to a common pre-defined dose of alcohol consumption. Comparing reaction times before and after consumption allows for interesting insights and suggestions regarding policy interventions. As expected, the results indicate that increased reaction times before consuming alcohol strongly affect post-consumption reaction times, while increased BrAC levels prolong reaction times; a 10% increase in BrAC levels results in a 2% increase in reaction time. Interestingly, individuals with faster alcohol absorption times perform better regardless of absolute BrAC level, while recent meals lead to higher reaction times and regular exercising to lower.

Keywords: alcohol; impaired driving; reaction times; simulator; random-parameter regression

1. Introduction

Alcohol impaired driving has been repeatedly linked to high accident involvement rates and severities (Mann et al., 2010; NHTSA, 2005; Williams, 2006). In the US, for example, alcohol-related accidents account for over 40% of total road accidents, while 32% of the fatally injured drivers have blood alcohol concentrations (BACs) over 0.08%. (NHTSA, 2004). In Greece, alcohol was detected in the blood of about 37% of the drivers involved in traffic accident during the years 1998–2000 (Papadodima et al., 2007). External costs of driving while intoxicated (DWI) include rescue and hospitalization expenses, property damages and loss of productivity, quality of life, and future earnings; Miller et al. (1999) estimated the cost/mile driven sober to be $0.07, while at BAC over 0.08 g/dL at $3.40.Young people who drink and drive have a relatively higher risk of crash involvement for all BAC ranges (Mayhew et al., 1986; Peck et al., 2008; Zador, 2000) and as a result lower BAC limits often apply. In Greece, the legal age for both drinking and driving is 18 years. A study of 241 Greek young drivers (aged 18 to 24 years) found that the young drivers whose dominant lifestyle trait was alcohol consumption had a higher risk of being involved in a road traffic accident (Chiliaoutakis et al., 1999). Worldwide, drivers between 20 and 29 have a three times higher crash risk involvement compared to drivers over 30 (Jenigan, 2001). The latter may be due to relative inexperience with drinking, with driving, and with combining these two (Williams, 2003).

Various road surveys, cross-sectional and case-control studies have shed light on the factors that influence alcohol-related fatalities. Significant predictors include road and driving conditions such as road type, lighting, and number of passengers. De Carvalho Ponce et al. (2011) found that most alcohol-related accidents in Brazil occur at nighttime and on weekends. In New Zealand, higher traffic volume and illuminated roads appear to be significantly safer (Keall et al., 2005), while the risk of fatal crashes at nighttime increases with the number of passengers for all BAC levels (Keall et al., 2004). Novice drivers are more affected by alcohol consumption (Peck et al., 2008), particularly during nighttime (Keall et al., 2004), while general risk-taking driver behavior aggravates alcohol impairment (Horwood and Ferguson, 2000). Authors focusing on the general tendency to drink and drive argue that in the US, members of fraternities, heavy drinkers, and people with a history of alcohol abuse are more likely to drink and drive (LaBrie et al., 2011).

Alcohol consumption and impaired driving have been extensively linked (Harrison and Fillmore, 2005). Alcohol consumption causes longer reaction times and breaking distances, inaccurate steering, and difficulties in perceiving roadway information (Kuypers et al., 2006); combining alcohol with drugs or fatigue further intensifies these effects (Banks et al., 2004; Ramaekers et al., 2000). Alcohol's changes in cognitive reaction include exacerbation of fatigue (NHTSA, 1998), decreased attention (Exum, 2006), changes in risk perception (Frick et al., 2000), and modification of cerebral activity (Aires Dominges et al., 2009). The magnitude of alcohol-related effects also depends on driver attributes such as weight, gender, drinking experience (Hiltunen, 1997), and beverage type (Richman and Warren, 1985).

Despite the obvious interest in DWI and in the factors that affect driver behavior under the influence of alcohol, very few studies have focused on the effect of differentiated BrAC levels on driving performance among young people, possibly because of the difficulty in collecting the necessary data. We explore young driver reaction times under the influence of alcohol by means of a driving simulator experiment. The simulator allows for the comparison of driving behavior before and after consumption, and for interesting insights to be made regarding alcohol impaired driving. This paper is organized as follow: section 2 provides a literature review on alcohol driving simulator experiments; section 3 describes the experimental procedure; section 4 provides information about the data used and the methodology employed; section 5 includes an overview of results; section 6 discusses the major findings and the limitations of the study.

2. Background on driving simulators experiments

Various studies have been using driving simulators to investigate drinking and driving given the possible advantages of a controlled environment for such investigations. The resulting BAC levels (as a percentage of alcohol in the blood) or the BrAC levels (micrograms of alcohol per 100 milliliters of breath) have been commonly used to measure alcohol levels. The amount of alcohol measured on the breath is generally accepted to be proportional to the amount of alcohol present in the blood. The most commonly used driving performance measures are: lateral position, speed and standard deviation of speed, steering wheel angle, off-road occurrences, and reaction time. This section summarizes driving simulator studies that fall in three large categories regarding the impairment factors considered: i) driver attributes, ii) alcohol dosage, iii) alcohol vs. or combined with other drugs, iv) Differentiated BACs according to driver attributes.

2.1 Driver attributes affecting DWI

Early simulator experiments in the US explored the effects of alcohol consumption on driving behavior among University students. Alcohol was found to impair abilities that are critical to driving such as braking and steering (Rimm et al., 1982), while "*high sensation seekers*" were more likely to drive dangerously compared to "*low sensation seekers*" (McMillen et al., 1989). The authors argued that "*high sensation seekers*" interpret alcohol consumption as a justification for risk-taking. Gawron and Ranney (1990) extended the age group to 55 to study the efficiency of spot treatments as potential alcohol countermeasures; however, their results did not support this hypothesis.

In another study, Leung and Starmer (2005) examined gap acceptance and risk-taking by young and mature drivers. 16 young and 16 mature drivers in Sydney were recruited for the experiment; they consumed 0.6 g (if female) or 0.7 g (if male) of alcohol per kg of weight. Driving tasks included other-vehicle detection, overtaking, and time-to-collision estimation. Detection times were significantly lower with age, alcohol consumption and lower approaching vehicle speeds particularly on curved road sections. Young drivers showed a greater tendency to engage in risky driving. In similar line of reasoning, Harrison and Fillmore (2005) tested the driving performance of 28 adults (21-31 years of age) in the US, under either an active dose of alcohol (0.65 g/kg) or a placebo. The objective was to examine whether 'bad' drivers are more likely to be impaired by alcohol. In parallel, a personal drinking habits questionnaire was completed, and a subjective intoxication degree was estimated. Significant within-lane deviation confirmed alcohol impairment for all participants. However, individuals with poorer baseline skills appeared to be more impaired by alcohol.

Arnedt et al. (2001) studied the effects of prolonged sleeplessness versus alcohol impairment among 18 Canadian males between ages 19 and 35. Driving performance was measured in terms of speed deviation, lane position, and off-road occurrences. The experiment showed that impairment is evident even for low BACs. The authors suggest that extending sleeplessness by 3hours can result to a reduced ability to maintain speed and road position equal to those found at the legal BAC limits.

2.2 Increasing alcohol dosage

Several authors tried to relate increasing alcohol dosage and resulting BACs to increasing driving impairment. In both Verster et al. (2009) and Wester et al. (2010), the authors used the divided-attention steering simulator (DASS) to examine the magnitude of impairment after administration of four different dosages of alcohol and placebo. Dose-dependent impairments were found for reaction times, while alcohol was found to increase distractibility and interference from secondary task stimuli, as well as to reduce attentional capacity and dual-task integrality.
Mets et al. (2011) performed a calibration study to test a standardized highway driving test scenario after administration of three different dosages of alcohol and placebo. Twenty-seven healthy young adults participated in this randomized, single-blind crossover trial. Subjects received alcohol to gain a blood alcohol concentration (BAC) of 0.05%, 0.08%, and 0.11%, or placebo–alcohol. Alcohol produced dose-dependent driving impairment. Standard deviation of lateral position and standard deviation of speed were significantly increased relative to placebo.
Allen et al. (2009) administrated 3 different doses of alcohol to 40 healthy social drinkers, individually tailored to their gender and weight. Participants performed a visual oddball (VO) task while operating a virtual reality driving simulator in a 3T functional MRI scanner. Behavioral analysis showed a dose-dependent linear increase in reaction time, with no effects associated with either correct hits or false alarms. In all dose conditions, driving speed decreased significantly after a VO stimulus. However, at the high dose this decrease was significantly less. Passenger-side line crossings significantly increased at the high dose. The authors concluded that drivers with high blood alcohol concentrations may be less able to orient or detect novel or sudden stimuli during driving.
Finally, Liu et al. (2010) investigated the effects of (1) different blood alcohol concentrations (BAC) of 0, 0.05, 0.08, and 0.10 percent and (2) post-alcohol impairment (where BAC equals 0%) on driving behavior through two sessions of simulated driving. All eight subjects showed lower performance for higher BAC levels with traffic sign distance estimation showing the most significant deterioration. Noticeably, no significant difference was found between drunk driving and post-alcohol driving, indicating that even in the post-alcohol situation, the impairment still remained significant enough to jeopardize traffic safety as much as it does in the case of drunk driving.

2.3 Alcohol vs. or combined with other drugs

Lenné et al. (2003) designed a simulator experiment to study the effects of the opioid pharmacotherapies methadone, LAAM and buprenorphine, by themselves, as well as combined with alcohol (around the 0.05% BAC). Participants were 10 methadone, 13 LAAM, 11 buprenorphine stabilized clients, and 21 non-drug Australians. Simulated driving skills were measured through standard deviations of lateral position, speed and steering wheel angle, and reaction time. The authors argue that BAC at 0.05% impairs all measurements of driving performance. Surprisingly, alcohol was found to have a more detrimental effect on speed and steer deviation on straight road sections.
Ronen et al. (2008) assessed the effects of marijuana compared to alcohol ingestion on driving performance, physiological strain, and subjective feelings. They recruited 14 Israeli students (25-27) who were recreational marijuana and alcohol users. Active and placebo dosages were administrated to identify differences in reaction time, number of collisions, average speed, lane position and steering variability. Alcohol consumption caused speed and reaction time increase,

sleepiness, and lack of attention. Following the same protocol and using similar equipment, Ronen et al. (2010) further investigated the effects of alcohol (BAC=0.05%), marijuana, and their combined consumption. Alcohol consumption was found to increase speed, while the combination of alcohol and marijuana appeared to have the most intense effect following intake. Lenné et al. (2010) designed a simulator experiment to study the combined effects of marijuana and alcohol (vs. only marijuana). To this end, they recruited both novice and experienced Australian drivers having a history of alcohol and marijuana consumption. Speed, headway, steering, reaction time, and lateral position data were used as driving performance indicators. Results showed that alcohol consumption is associated with speed increases and lateral position variability, but it does not affect reaction time nor does it produce synergistic effects when combined with marijuana. The authors attribute the latter to the relatively low alcohol dosage (ethanol of app. 0.5g/kg).

Finally, Simons et al. (2011) assessed the effects of alcohol, dexamphetamine and the combination of both on simulated driving and cognitive performance. Eighteen subjects participated in a randomized, crossover, placebo-controlled study; fundamental driving skills and risk-taking behavior were assessed in a driving simulator. Subjects using alcohol showed a significantly larger mean standard deviation of lateral position. Interestingly, performance of vigilance and divided attention tasks was significantly impaired in the alcohol condition and, to a lesser degree, in the dexamphetamine and alcohol condition.

2.4 Differentiated BACs according to driver attributes

Jelen et al. (2011) explored the influence of alcohol intoxication on right hand movement during gear changing and car operating among 8 participants. They observed a large variability in BACs as well as large intra-individual reaction time variability. Large differences between the expected and the measured BAC were found, while the maximum BAC was reached 30 to 60 minutes after consumption. Furthermore, empirical evidence indicated a strong relationship among the measured BAC, time of the day, and stomach content.

Despite the extensive work on simulated DWI, very few studies have considered the differentiated effect of the same dose of alcohol (vs. the same BAC) on driving performance while considering driver attributes. In addition, most simulator experiments have included a limited number (<20) of drivers. In this paper, we extend research by exploring the impact of a common pre-defined dose of alcohol to driving performance, while using the resulting BrAC level as a contributing factor instead of a given input. We perform the experience among a population of 49 European drivers while observing the time variation of BrAC.

3. Experimental Design

3.1 Participants

Participants were voluntarily recruited among the students and employees of the Athens Technological Institute and the National Technical University of Athens. They were motivated by the acquaintance with the simulator equipment, by the drinking experience or by both. They were subjected to a common pre-defined dose of alcohol consumption, underwent two driving sessions, and completed a questionnaire. All subjects (N=49, F(male)=53,1%)) were non-abstaining drinkers holding a valid driver's license, followed no medical treatment and were between the ages of 20 and 30 (mean age=23.2, SD=2.7). Other authors have also concentrated on the same age group for studying young driver alcohol impairment (Harrison and Fillmore, 2005, as an example). The racial makeup of the sample was 100% Caucasian and consisted of 32.7% self-reported heavy drinkers (alcohol consumption higher than 3 times a week), 47.0 % light drinkers (consumption lower that twice a week), and 8.2% occasional-drinkers (consumption less than twice a month).We note that all drivers provided informed consent prior to participating and did not leave the laboratory before their BrAC level was zero. Participants were also requested to abstain from consuming drugs or alcohol for a minimum of 18h prior to the experiment. Any subject who tested positive for the presence of alcohol prior to the experiment was excluded from the study. All sessions took place during late evening hours to approximate actual drinking and driving conditions.

3.2 Laboratory settings

The experiment was held at the Department of Transportation Planning and Engineering of the National Technical University of Athens, Greece. We used a driving simulator (Foerst F12PT-3L40), along with a certified breath alcohol test device (Lion SD-400). The simulator included a full car cabin (Ford), while visual images were projected onto three monitors resulting in a field view of 135^0. The driving cabin was equipped with usual functional car commands and features such as indicators, pedals, steering wheel, gearbox, dashboard, handbrake, car seat, and seatbelt. Driver response is recorded at any change in the measurements (e.g. angles in degrees from -180 to +180, pedal pressure from 0 to 100%, braking is recorded from brake pedal press).

3.3 Experimental procedure

The experiment was designed following a 5-stage procedure.

1. Subjects were briefed on the experimental procedure and requirements. They were introduced to the testing equipment (alcoholmeter and simulator), and had 3 minutes of free driving to get familiarized with the simulator. During the familiarization drive, they performed simple tasks (successfully starting up, changing gears, and breaking) and drove freely in the absence of triggered event occurrences. They were also instructed to complete a questionnaire regarding their physical state (e.g. fatigue, hours of nighttime sleep), personal attributes (e.g. age, weight, gender), travel habits (e.g. annual mileage), crash involvement history (e.g. number of accidents, whether at fault, severity outcome), drinking habits (e.g. frequency, quantity), and driving behavior (average travelling speed on highways, DWI, etc.).
2. Subjects underwent a 4-minute session of free driving under normal weather conditions, in the presence of on-coming traffic, and in a small-sized city environment. The road network included urban arterials and local roads; traffic control included roundabouts, signalized and non-signalized intersections; the on-coming traffic included both private cars and heavy vehicles. As it was a time-defined experiment, the total trip length varied according to the travelling speed, the number of off-road occurrences, the time needed to check when approaching non-signalized intersection. Eight predefined events (sudden opening of the door of a parked vehicle or animal entering suddenly the road) - triggered randomly by the operator - allowed for reaction times estimation. Triggering events did not occur at the same time/point to avoid anticipation/learning effects. Participants were not aware of the exact number and type of triggering events. Operators were instructed not to follow specific patterns (for example, equal spacing) in

the events' generation. This driving test served as a baseline reaction time measurement in order to assess driving skills while sober.
3. Subjects ingested 100 ml of liquor (approximately 40ml of ethanol) within a short period of about 10 minutes. Liquor included vodka (F=28%), whisky (F=48%) or gin (F=24%), diluted (e.g. with fruit juice) or straight, according to personal preferences. All such differentiations were recorded and statistically examined for possible influences on BrAC and driving performance; however, they were not to be statistically significant. All participants were administered equal ethanol quantity regardless of their physical characteristics (weight), so as to obtain a range of BrACs. After a 20 min post-ingestion interval, subjects provided breath samples every 20 minutes and over a 1.3 hour period (4 times overall), to observe BrAC variation overtime.
4. Subjects repeated stage 2 driving session one hour after liquor administration and while still being intoxicated. They were again asked to drive freely in a small-sized city environment. The same number of triggering events was used to estimate reaction times. These events were again triggered randomly by the operator in order to exclude anticipation/learning effects.
5. Subjects waited in a separate room until they produced a zero BrAC sample. While waiting, they could plot an indicative personal BrAC to time curve on a PC available for that purpose. They could thus observe the differences among participants, as well as their personal metabolism rate and reaction to alcohol consumption.

3.4 Performance measures

Driving performance (before and after intoxication) was assessed by driver reaction times to triggering events. Average time lag (in milliseconds) between triggering event occurrences and driver reaction (be it braking or steering) served as driving performance indicator. However, the simulator does not keep record of the type of reaction triggered by each event. We note that reaction time (RT) is critical to road safety and has been used as a performance measure in previous simulator experiments (Lenné et al, 2003; Leung and Starmer, 2005; Ronen, 2008). Before performing the experience, we held a few pilot sessions during which we reversed the sessions' order (intoxicated - unintoxicated) to check for possible practice/learning effects. We did not observe significant differences. Even if such effects do exist: (i) they come to strengthen our overall conclusion regarding alcohol impairment, and (ii) it is the case across all individuals and, so, inter-sample comparisons are not necessarily biased.

4. Data and Methodology

4.1 The Data

Reaction time (M=1.1 sec, SD=0.3) while intoxicated was used as the dependent variable in our analysis. Questionnaire data and breath test results served as independent variables. Table 1 provides a description of all independent variables considered along with summary statistics. We created a dummy variable '*BrAC1/3*'to capture the absolute difference between the third (right before the driving while intoxicated session) and the first (immediately following alcohol ingestion) breath test results. Interestingly, the positive sign for 41% of the cases indicates that BrAC may continue to rise for as long as 1h following ingestion; the average value of 1.2 and S.D. of 0.6 indicate strong heterogeneity across individuals regarding BrAC time variation.

Table 1 Explanatory variables in reaction time analysis

Variable	Type	Summary Statistics[1]	Description
Fatigue and sleepiness			
Sleeping hours	continuous	M=7.7, SD=2.1	hours of nighttime sleep
Hours awake	continuous	M=7.8, SD=2.6	hours since morning wake-up
Time to last meal	continuous	M=6.5, SD=6.6	hours since last meal
stated fatigue	dummy	F(0)=53.1%	=0 if tired; =1 otherwise
Personal data			
weight	continuous	M=71.1, SD=14.9	weight in kg
Age	continuous	M=23.2, SD=2.6	age in years
height	continuous	M=174.3, SD=9.4	height in cm
driving experience	continuous	M=4.4, SD=3.1	years since driver’s license
being female	dummy	F(0)=46.9%	=0 if female; =1 otherwise
having eyesight problem	dummy	F(0)=53.1%	=0 if yes; =1 otherwise
No regular exercise	dummy	F(0)=40.8%	=0 if no regular physical exercise; =1 otherwise
1-2h of weekly exercise	dummy	F(0)=26.5%	=0 if yes; =1 otherwise
>4h of weekly exercise	dummy	F(0)=16.3%	=0 if yes; =1 otherwise
Light regular drinker	dummy	F(0)=85.7%	=0 if 1- 2 drinks/week; =1 otherwise
Breath test experience	dummy	F(0)=46.9%	=0 if previous experience; =1 otherwise
Driving behavior			
Infraction history	dummy	F(0)=26.5%	=0 if previous infraction; =1 otherwise
Accident history	dummy	F(0)=53.1%	=0 if previous involvement; =1 otherwise
Average speed on highways	continuous	M=105.4, SD=24.8	average travel speed (km/h)
Speed limit violation	dummy	F(0)=12.2%	=0 if ‘average speed on highways’>130; =1 otherwise
Low self-confidence	dummy	F(0)=20.4%	=0 if low; =1 otherwise
Never drink and drive	dummy	F(0)=28.5%	=0 if never; =1 otherwise
Sometimes drink and drive	dummy	F(0)=61.2%	=0 if sometimes; =1 otherwise
Breath test results			
BrAC-1	continuous	M=0.3, SD=0.1	breath test results (mg/L) 20 min after ingestion
BrAC-2	continuous	M=0.3, SD=0.1	breath test results (mg/L) 40 min after ingestion
BrAC-3	continuous	M=0.2, SD=0.1	breath test results (mg/L) 60 min after ingestion
BrAC-4	continuous	M=0.2, SD=0.1	breath test results (mg/L) 80 min after ingestion
Average BrAC	continuous	M=0.2, SD=0.1	average result for all breath tests
BrAC 3-1	dummy	F(0)=59.2%	=0 if *(BrAC-3)-(BrAC-1)*<0; =1 otherwise
BrAC 1/3	continuous	M=1.2, SD=0.6	ratio of first to third breath test results

[1] F: frequency
M: average value
SD: Standard Deviation

4.2 Data Analytic Technique

Multiple linear regression is commonly used to model the relationship between a continuous dependent variable and several regressors that are thought to covary. Subject reaction time following alcohol administration is a continuous nonnegative variable and can be reasonably assumed to covary with experimental data (such as BrACs, subject age and physical condition). Following Washington et al. (2010), reaction time can be modeled as follows:

$$Y_i = \beta_0 + \beta_j X_{ij} + \varepsilon_i \quad (1)$$

where Y_i is reaction time for subject *i*=1,2,…,49, β_0 is the constant term, β_j stands for the coefficients to be estimated for the *j*=1,2,…,*ρ* independent variables considered, and ε_i is the disturbance term for individual *i*.

The functional form of the multiple linear regression in Eq. (1) assumes that the estimated parameters are the same for all observation; however, initial regression results indicated significant heterogeneity among subjects and raised certain questions regarding the validity of such a fixed parameter assumption which, if violated, may result in inconsistent estimates. To relax the fixed-parameter restriction, a random parameter linear regression model was instead used (Washington et al., 2010):

$$Y_i = \beta_{0i} + \beta_{ij} X_{ij} + \varepsilon_i \qquad (2)$$

$\beta_{ij} = \beta_j + \varphi_i$, with φ_i a randomly distributed term. The distribution of the φ term across individuals is to be specified along with the other model parameters (possible distributions include Normal, Uniform and Triangular). The random-parameter model randomizes the parameters to allow for the influence of the independent variables affecting reaction time to vary across individuals (for more information and a detailed discussion on random parameter models see Anastasopoulos and Mannering 2009 and 2011).

5. Results

5.1 Model estimation

Two fixed- and two random-parameter models were used to model reaction times and alcohol-related variables while controlling for driver attributes. We also estimated two separate models; in the first type, the BrAC level was the value obtained at the third breath test was used (right before driving while intoxicated and 1h following alcohol ingestion). In the second, variable '*BrAC1/3'* was used in order to observe differences with respect to alcohol absorption rates for the subjects (joint consideration of all alcohol-related variables was rejected because of multicollinearity concerns). The fixed-parameter specification was estimated using ordinary least squares (OLS), while maximum likelihood estimation was used to estimate the underlying population parameters for the random parameters model. We note that simulations were based on random draws with OLS parameter estimates serving as starting values. Normal, triangular and uniform distributions were considered for the functional form of the random parameter density functions.

Model estimation results are shown in Tables 2 and 3; omitted variables were excluded from the final models because of low statistical significance. All estimated parameters included in the final models are statistically significant at the 95% confidence level. The standard deviation for the distribution of the random parameters was significantly different from 0 for all the variables included in the random-parameter models. Elasticities are estimated for all continuous variables to assess reaction time sensitivity with respect to changes in the regressors.

In all cases, random-parameter models significantly outperform fixed-parameter models based on the likelihood ratio test. The test yields values higher than the X^2 critical values, indicating a confidence that the random parameter models outperform the fixed parameter specification. We also note that, besides statistical fit, the two model specifications yield – in some cases - qualitatively and quantitatively different results for the parameter estimates. For example, variables '*regular light drinker'* and '*low self-confidence*' were found to be statistically significant only in the random-parameter analysis.

Table 2 Model Estimation Results for Model Type 1

	Fixed Parameters			Random Parameters			
Variables	coefficient	t-statistics	elasticity	coefficient	t-statistics	S.D.[a]	elasticity
constant	0.41	1.94		0.93	16.21	0.04	
RT-bef	0.47	3.83	0.54	0.10	2.56	0.18	0.12
BrAC-3	0.38	0.95	0.08	0.89	7.08	0.06	0.20

Variables	Fixed coefficient	Fixed t-statistics	Fixed elasticity	Random coefficient	Random t-statistics	S.D.[a]	Random elasticity
>4h of weekly exercise	0.15	1.87		0.15	7.95	0.03	
Speed limit violation	0.14	-1.33		0.15	-6.31	0.11	
Time to last meal	-0.01	-1.12	0.03	-0.01	-3.68	0.01	0.04
Low self-confidence	-0.01	0.09		0.21	-9.37	0.05	
Regular light drinker	0.09	1.08		-0.10	-4.34	0.26	
Number of observations					49		
Log-likelihood at zero LL(0)					-3.32		
Log-likelihood at convergence LL(β)			12.1	28.81			
Number of parameters			8	17			
R-squared			0.47				
Likelihood-ratio test				Random vs. fixed parameters			
X^2=-2(LL(β_{fixed})-LL(β_{random}))				33.42			
Critical X^2 (0.9995 level of confidence and v=9 d.o.f.)				29.67			

[a]Standard deviation of parameter distribution

Table 3 Model Estimation Results for Model Type 2

Variables	Fixed Parameters			Random Parameters			
	coefficient	t-statistics	elasticity	coefficient	t-statistics	S.D.[a]	elasticity
constant	1.47	8.09		1.36	21.66	0.04	
BrAC1/3	-0.14	-2.36	0.14	-0.13	-8.10	0.04	0.14
Never drink and drive	0.21	-2.76		0.11	-6.20	0.11	
>4h of weekly exercise	0.31	3.36		0.29	10.17	0.05	
Speed limit violation	0.25	-2.32		0.22	-5.57	0.16	
Time to last meal	-0.01	-1.62	0.42	0.01	1.83	0.00	0.02
Low self-confidence	0.08	-1.01		0.17	-6.59	0.02	
Regular light drinker	0.03	0.29		0.06	1.50	0.12	
Number of observations		49					
Log-likelihood at zero LL(0)		-3.32					
Log-likelihood at convergence LL(β)			8.05	23.71			
Number of parameters			8	17			
R-squared			0.37				
Likelihood-ratio test			Random vs. fixed parameters				
X^2=-2(LL(β_{fixed})-LL(β_{random}))			31.32				
Degrees of freedom			v=17-8=9				
Critical X^2 (0.9995 level of confidence)			29.67				

[a]Standard deviation of parameter distribution

In the first model type, we focus on the relationship between reaction time while intoxicated (*RT_after*), reaction time before drinking (*RT_bef*) and BrAC level. Results indicate that being a regular light drinker, having low self-assessed driving skills, driving regularly at speeds beyond the legal limits, and exercising for less than 4h per week significantly increases reaction time while intoxicated. Increased BrAC levels are related to increased reaction times with an elasticity of -0.2. Reaction time decreased with lower times since the last meal, but with lower elasticity than the BrAC levels. Finally, increased reaction times while driving without alcohol (*RT_bef)* is strongly related to increased reaction times when driving under the influence (*RT_after*). All regressors were significant in the random parameter model with '*RT_bef', '>4h of weekly exercise', 'time to last meal', 'low self-confidence', and 'regular light drinker'* following the normal distribution, 'BrAC-*3'* following the uniform distribution, and '*speed limit violation'* following the triangular distribution.

In the second model type, we focus on the relationship between reaction time while intoxicated ('*RT_after'*), and the ratio of breath test results ('*BrAC1/3'*). Empirical results suggest that low –

self assessed - driving skills, driving regularly at speeds beyond legal limits, exercising for less than 4h per week, and never driving after drinking significantly increase reaction times while intoxicated. In contrast to the first model type, light drinkers and recent meals seem to result in decreased reaction times. Furthermore, increasing BrAC ratios (‘*BrAC1/3’*) result in lower reaction times; all regressors were found to have random parameters.

5.2 Experiment-specific driver data

Among all variables related to experiment-specific data, reaction time before intoxication and the time elapsed since the last meal were found to be significant. Instead, hours of nighttime sleep and hours since morning wake-up do not appear to statistically influence reaction time. This finding contradicts some previous research (Arnedt et al., 2001), where prolonged sleeplessness was found to increase alcohol’s effects; we note though that we also considered additional fatigue-related variables such as ‘*time to last meal*’ and ‘*RT-bef’*.

Empirical results from the first model indicate that ‘*time to last meal*’ has a random parameter with a mean of -0.006 and a SD of 0.009; this implies that for 75% of the subjects recent meal has an increasing effect on reaction time. This finding can be explained by the overall fatigue resulting from the additive effect of eating and drinking. Interestingly, in the second model, ‘*time to last meal*’ has a positive random coefficient of 0.003 and an SD of 0.004; this suggests a possibly strong heterogeneity between individuals that would have been neglected under a fixed-parameter approach. We believe that further investigation is needed to fully interpret the relationship between meals timing and reaction times.

Empirical results also indicate that ‘*RT-bef’* significantly influences reaction time while intoxicated. This clearly suggests that higher baseline reaction times correspond to higher reaction times after drinking. The corresponding random coefficient is normally distributed with a mean value of 0.102 and an SD of 0.181; the latter indicates that for 75% of the sample, increased values for initial reaction times are related to increased reaction times following intoxication. Similar findings were reported by Harrison and Fillmore (2005) where individuals with poorer baseline skills were found to be more affected by alcohol. For the remainder 25% of the subjects, increased baseline reaction times resulted in decreased reaction times after drinking; this rather counter-intuitive finding may be a result of low-dosage (a similar hypothesis was formulated by Lenné et al., 2010). We also note that the elasticity of ‘*RT-bef’* is lower than‘*BrAC-3’,* indicating that changes in BrAC levels have a stronger effect on reaction times compared to baseline driving skills.

5.3 Personal data

Regarding personal data, two variables were found to significantly affect reaction times in all random-parameter models: physical exercise and drinking frequency. Both variables were not statistically significant under the fixed-parameter modeling approach. Variables related to weight, age, and sex were not found to be significant; measured BrAC is believed to ‘absorb’ all relative variance and indirectly – at least - capture such driver attributes.

Exercising for over 4hrs per week reduces reaction times. This is a rather intuitive finding suggesting that ‘fit’ individuals respond quicker to external stimuli even when intoxicated. This finding could be also explained on a metabolic basis as individuals engaged in regular and intense training programs exhibit an elevated resting metabolic rate (Tremblay et al., 1985). Finally, another possible interpretation is that individuals that exercise regularly are in an overall healthier condition (Penedo and Danh, 2005; Warburton, 2006). In any case, further research is needed to explain this finding. The corresponding coefficient was found to follow the normal distribution with a relatively low SD compared to the mean, suggesting that this finding holds for the entire sample.

In both model types, being a regular light drinker was found to have a significant impact on reaction times. In the first model type, light drinkers show reduced reaction times compared to all other drinking frequencies (both occasional and heavy). Both occasional and heavy drinkers drink and drive are less experienced in DWI compared to light drinkers. This implies that drivers used to driving under the influence negotiate better with unexpected road hazards; however, the latter is restrained by an upper limit of two drinks per week. The random coefficient has a mean of -.103 and an SD of 0.255, indicating that the distribution is positive only for 66% of the subjects. The second model type indicates that light drinkers show increased reaction times when compared to all other drinking frequencies. Again, the corresponding random coefficient is normally distributed with a mean of 0.062 and an SD of 0.120 indicating that the latter holds for 65% of the subjects.

5.4 Driving Behavior

Several variables related to self-reported driving behavior were examined regarding their influence on reaction times following intoxication. Results indicate that a – self-reported - average highway travelling speed over the maximum legal limit seems to correspond to longer reaction times. This finding suggests that driving while intoxicated is related to general risk-taking behaviors as suggested by Horwood and Ferguson (2000). In all random parameter models, we find that drivers, who self-assess their skills as low, have longer reaction times compared to more self-confident drivers. We finally find that drivers who report never to drink and drive have significantly longer reaction times compared to drivers that drive while intoxicated on a 'regular' basis.

5.5 BrAC

Breath test results enabled us to consider several BrAC-related variables; '*BrAC-3'* and '*BrAC1/3*' were found to be significant. As expected, the BrAC appears to have a strong relationship with driving performance as it directly affects cognitive abilities by exacerbating the effects of fatigue (NHTSA, 1998), decreasing the attention (Exum, 2006), changing risk perception (Frick et al., 2000), and modifying cerebral activity (Aires Dominges et al., 2009). The elasticities for both variables are rather high (0.2 and 0.14 respectively), verifying the increased sensitivity of reaction time to changes in alcohol dosage and BrAC levels. Results suggest that high BrAC levels -as measured 1 hour after alcohol consumption and just before driving ('*BrAC-3'*)- are linked to longer reaction times. Tzambazis and Stough (2000) conducted a psychometric experiment and concluded that increasing BrAC levels impair speed of information processing, simple reaction time, choice reaction time and higher-order cognitive abilities; similar findings can be found in other medicine-oriented experiments.

Results also indicate '*BrAC1/3'* to be significant; greater values of the BrAC ratio variable are related to lower reaction times. Greater values for '*BrAC1/3*' imply that the initial BrAC level has been significantly changed towards lower values, while the opposite is implied by lower values. Figure 1 depicts probable BrAC time evolution with a biphasic effect on cognitive abilities for the ascending and the descending parts (King et al., 2002; Pihl et al., 2003). Figure 2 provides the empirical curve for the entire sample. In general, increased BrAC ratios ('*BrAC1/3'*) indicate narrower curves and quicker BrAC evolution overtime. The corresponding coefficient has a mean of -0.133 and an SD of 0.044. This finding suggests that individuals with narrower curves (faster alcohol absorption) show better driving performance regardless of their absolute BrAC level.

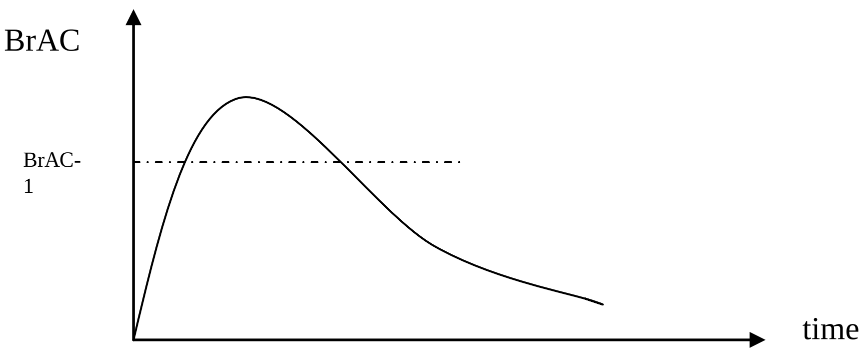

Figure 1 Qualitative BrAC to time curve

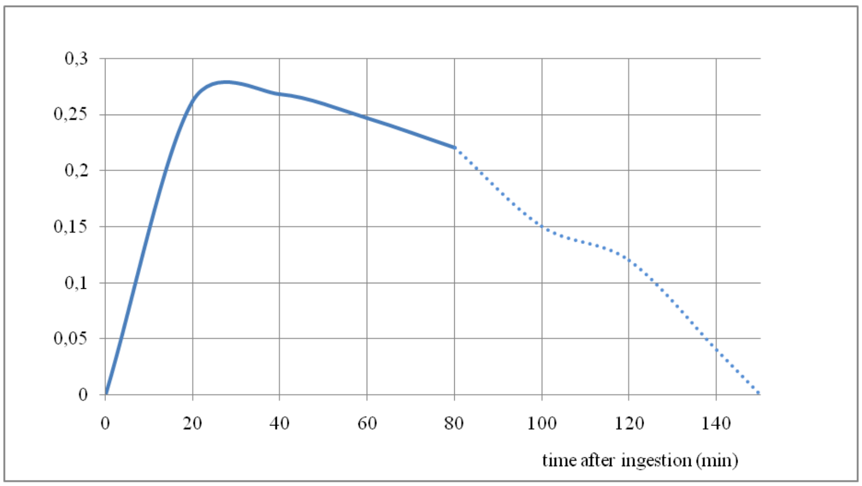

Figure 2 Empirical BrAC (mg/L) to time (min) curve for the entire sample

Most importantly, BrAC test results and BrAC evolution over time were largely different per individual. In Figure 3, we plot individual BrAC-time curves for all subjects. We note that in Greece, the BrAC legal limit is 0.25 mg of alcohol per 1 liter of breath. The respective limit for BAC is 0.50 g/l. Figure 3 comes to verify our initial hypothesis that there exists strong heterogeneity across individuals regarding both BrAC absolute values and BrAC time variation. This heterogeneity should be accounted for when undertaking simulator experiments. In the case of simulator experiments considering equal BrACs across individuals, significant bias may occur as the BrACs evolve differently during the driving session. Furthermore, simulator experiments targeting to specific BrAC levels risk producing unrealistic cognitive situations by administrating excessive alcohol quantities to individuals showing good metabolism performance.

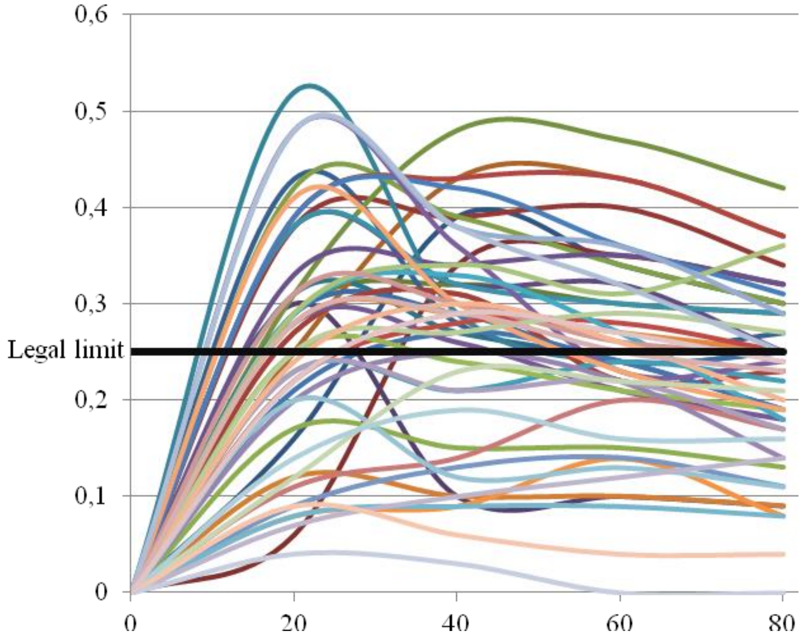

Figure 3 Empirical BrAC (mg/L) to time (minutes) curve per subject

6. Conclusions

We explored alcohol impairment through a driving simulator experiment focusing on younger drivers as there is empirical evidence indicating a significantly stronger effect of alcohol on young driver behavior as well as higher accident involvement rates. In contrast to most studies where behavior has been studied under an equal-BrAC-level hypothesis, we administrated the same alcohol quantity to all subjects. We believe that the latter better approximates actual drinking habits of social drinkers following prevalent drinking patterns (on a typical day, young social drinkers in Athens usually have one or two drinks before driving back home). In addition, we considered various driver attributes that were found to impact alcohol impairment.
Accounting for heterogeneity among subjects as well as for BrAC time-variations allowed for better reaction time estimation both before and after intoxication. We made the hypothesis that personal data (drinking and driving habits) and BrAC level explain post-consumption reaction times. We didn’t limit our research to the relationship between pre- and post-consumption reaction times because we assume a non-linear relationship between personal data, resulting BrAC and impaired driving performance. As an example, a fit individual may have slower reaction times (compared to the sample of drivers) when sober and quicker reaction times (compared to the sample of drivers) when DWI.
Results indicate that exercising for less than 4h per week significantly increases reaction times. The effect of being a light drinker and having had a recent meal is largely differentiated across individuals; similar were the findings in Jelen (2011). As it could have been anticipated, higher BrAC levels are related to slower reaction times (a 10% increase in BrAC levels results in a 2% increase in reaction time). Furthermore, variations in BrAC levels have a stronger effect on reaction times compared to baseline driving skills. Most importantly, BrAC level evolution overtime is strongly related to faster reaction times and, thus, better driving performance.

Individuals showing faster alcohol absorption perform better regardless of their absolute BrAC level.

Overall, these results bring to light three important points that have been largely unaddressed: (i) the significant difference in resulting BrAC levels for the same quantity of alcohol consumed, (ii) the strong heterogeneity regarding post-alcohol driving performance among individuals, and (iii) the differentiated BrAC level evolution overtime. These findings suggest that it is practically impossible for an individual to 'estimate' his BrAC level and to make a rational decision on whether to drive or not. In addition, breath tests performed by traffic police do not include information about future BrAC evolution that may increase abruptly in a few minutes time. Besides, breath-test results are not indicative of the driving impairment level. In conclusion, this research highlights the need for targeted measures to young drivers, questions the utility of legal alcohol limits beyond zero, and stresses the importance of reconsidering policy tolerance towards DWI.

As a caveat, we note that our research suffers from several limitations. First, simulating driving only approximates actual road and driving conditions and is unable to capture the complexity of real-life procedures such as decision-making and hazard perception. However, it can be reasonably assumed that relative performance (sober vs. intoxicated for example) on the simulator can reflect alcohol impairment. Moreover, the sample size could be larger and additional performance measures (such as average travel speed and vehicle positioning) could have been used to better assess driving performance. In addition, a post-alcohol driving session could have been considered as there is evidence indicating impairment even for post-alcohol BrAC levels equal to zero (Liu et al., 2010). Furthermore, triggering events were randomly produced by the operator in order to avoid anticipation effects. Nevertheless, the operator's choice of time and driving situation may introduce bias to reaction estimations. Automatically generated triggering events could contribute in better estimation results. Another confounding factor may be the progressive declination of driving performance due to fatigue. Even if we performed few-minute sessions, this potential effect cannot be excluded. We intend to continue our research towards these directions.

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