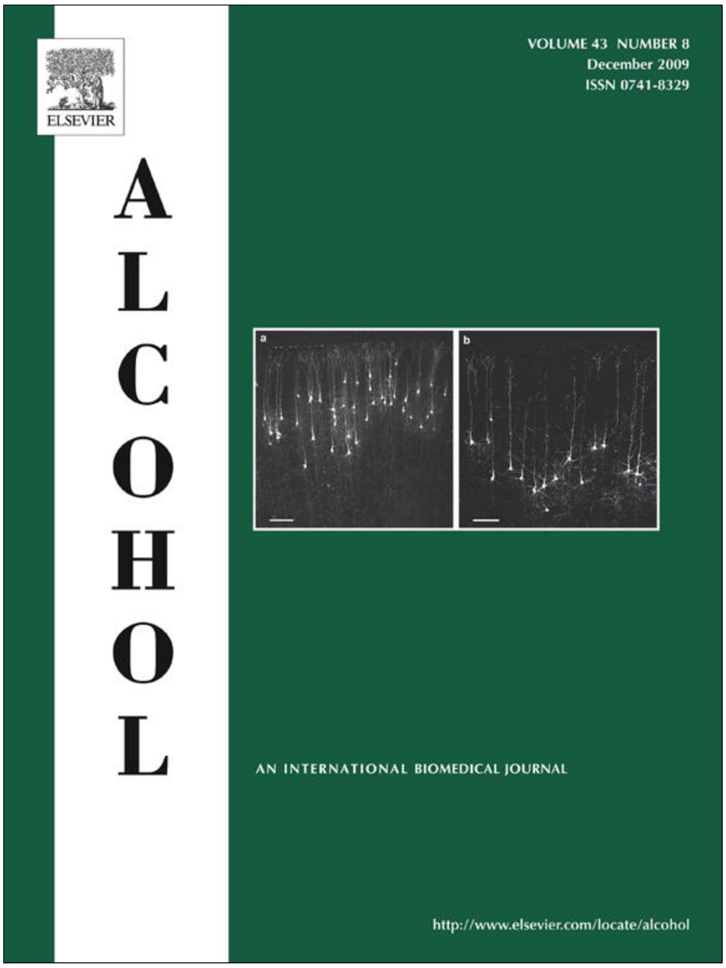
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Drinking and driving: a decrease in executive frontal functions in young drivers with high blood alcohol concentration

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Abstract

This study correlated the executive frontal functions with blood alcohol concentration (BAC) in night drivers in a Brazilian city. Of 592 drivers randomly recruited between December 17, 2005 and May 5, 2006, during nighttime hours on main streets or avenues with intense vehicle traffic in Vitória, Brazil, 444 had the BAC determined by a portable digital breath alcohol analyzer and 389 were submitted to a frontal function examination by a frontal assessment battery (FAB). A high percentage (24.4%) of drivers presented alcohol in their blood. Most of these drivers were male (82%), and nearly half (43.7%) were young adults (aged between 20 and 30 years). The results showed an inverse relationship between the BAC and FAB total scores, with a higher BAC corresponding to a smaller FAB total score, delineating a progressive decrease in frontal function with increasing concentrations of alcohol. The most intriguing result was that alcohol-induced impairment on frontal executive function was particularly important in young adults, and more specifically in the motor programming subset of FAB, an executive function highly involved in driving skills. Considering the worldwide evidence of the high-risk involvement of youth in automobile crashes, the effects of alcohol in young adults need to be more thoroughly examined by cognitive studies, and more direct preventive solutions need to be taken focusing on this age range.

Keywords: Alcohol; Executive functions; Drivers; FAB; BAC

Introduction

Drinking alcoholic beverages is a common characteristic of social meetings in many parts of the world. However, this habit has a high-risk factor for leading to adverse social and health consequences, including injuries from traffic accidents. In 2004, the World Health Organization (WHO) estimated that nearly 2 billion people worldwide consumed alcoholic beverages, and 76.3 million had diagnosable alcohol use disorders (WHO Global Status Report on Alcohol, 2004). Recently, the Assistant Director-General of the WHO's Noncommunicable Diseases and Mental Health Cluster estimated that every year at least 2.3 million people die from alcohol-related causes, stating that the harmful use of alcohol is a leading risk factor for premature death and disability in the world (WHO Sixtieth World Health Assembly, 2007).

Epidemiological studies show that the alcohol use has been increasing, in particular among young individuals (Galduróz and Caetano, 2004). The use of alcohol has been linked to different manifestations of violence, such as intimate partner violence, familiar violence, suicide, and injuries or deaths because of traffic crashes (Brent et al., 1987; McMillan and Lapham, 2006; Murdoch et al., 1990; Phebo and Dellinger, 1998). In addition, an increased risk of vehicle crashes has been related to increasing blood alcohol concentrations (BACs) (Reis et al., 2006) in combination with some specific sociodemographic characteristics. As a result, studies have shown that young male drivers, particularly those aged between 22 and 45 years, are more prone to be involved in alcohol-related fatal crashes (Hingson and Winter, 2003).

Alcohol-related brain damage, with impairments to frontal executive function, has been shown to occur mainly during the late stages of alcoholism (Ciesielski et al., 1995; Garrido and Fernández-Guinea, 2004). In addition, previous studies have demonstrated that acute alcohol

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ingestion compromises memory and attention (Duka et al., 2001; George et al., 2005; Weissenborn and Duka, 2000). However, fewer studies have precisely examined the acute effects of alcohol on executive function. Frontal executive abilities include abstract reasoning, sustained and selective attention, reaction time, mental flexibility, motor programming and executive control of action, resistance to interference, inhibitory control, and environmental autonomy (Lezak, 1995).

Weissenborn and Duka (2003) investigated the effect of the acute ingestion of 0.8 g/kg (compared with placebo) in social drinkers aged between 18 and 34 years, and found that subjects under the influence of alcohol showed a decrease in certain cognitive abilities related to executive functioning. During tests of cognitive function, the subjects had a decrease in the number of solutions with the minimum number of moves in a planning task, a decrease in the length of thinking time before initiating a response, coupled to an increase in the subsequent thinking time for the same task, and they also recognized fewer items in the spatial recognition task.

Significant impairments in executive cognitive functioning were also found by Pihl et al. (2003), using a computer program that contained six tasks: four variations of the Random Object Span Task and two variations of the Acquired Association Task. The deficit in function was especially evident on the descending limb of the curve of BAC in young subjects (mean of 21.02 years old) under a moderate dose of alcohol (1.32 mL of 95% alcohol/kg).

On the rising limb of the curve of BAC, following the ingestion of moderate doses (0.62 or 0.8 g/kg) of alcohol by young subjects (mean age of 19.8 years old), Hernández et al. (2006) found an impairment in the premotor (cognitive) reaction time, which is the amount of time required to perceive and interpret a stimulus and decide on a response before any movement. However, there were no changes in the motor reaction time, the elapsed time associated with the execution of the response.

Most of frontal executive cognitive processes are highly related to driving skills, because they mediate motor responses to visual, auditory, and tactile information when someone is driving a motor vehicle (Brouwer et al., 2002; Lengenfelder et al., 2002).

The frontal assessment battery (FAB) developed by Dubois et al. (2000) is a brief instrument that is very sensitive to frontal lobe dysfunction (Dubois et al., 2000). It takes approximately 10 min to administer, and can be easily applied at bedside (Appollonio et al., 2005; Dubois et al., 2000). This battery consists of six subsets screening the global executive dysfunction: conceptualization, mental flexibility, motor programming, sensitivity to interference, inhibitory control, and environmental autonomy (Dubois et al., 2000).

This study determined if there was a correlation between the executive frontal functions assessed by application of the FAB and BAC (determined by a portable digital breath alcohol analyzer) in drivers randomly selected during the night on main streets or avenues with intense traffic in the city of Vitoria, Brazil.

Material and methods

Subjects

Drivers were randomly recruited between December 17, 2005 and May 5, 2006, by agents of the traffic police during nighttime hours (from 10 p.m. to 3 a.m.) on Thursdays, Fridays, or Saturdays at strategic points on main streets or avenues with intense vehicle traffic in Vitória, Espírito Santo, Brazil.

Ethics approval was provided by the Brazilian Institutional Review Board at the Federal University of São Paulo, SP, Brazil. The study was conducted in strict adherence to the Declaration of Helsinki and is in accord with ethical standards of the Committee on Human Experimentation of the Federal University of Espírito Santo, ES, Brazil.

Procedures

General procedure

At the time this study was conducted there was a well-publicized campaign conducted during the nighttime hours on weekends by the Motor Vehicle Traffic State Department and the Military Police Department to determine the presence of alcohol in nocturnal drivers with the objective of reducing the incidences of traffic accidents involving alcohol use. This campaign started on August of 2004 and remains in effect today. Thus well prior to the present study, the local population was aware of the existence of this campaign. Understanding the importance of this study, the state department of traffic and the military police allowed our research team to be near (approximately 100 m apart) but not with or within them (they had their own team work). The traffic agents were asked to count five vehicles they were selecting for their own operation and redirect always the sixth with no specific criteria (including cars, trucks, motorcycles, etc.) to our research group. The selected vehicles were politely asked to slow down and were directed toward us at the nearby location with no direct interaction with the traffic police and the driver.

A member of our research team first approached these drivers, explaining the whole purpose of the study. It is stressed that the traffic police team was not involved in the data collection, they were not able to see or identify the occupants of the vehicle. Nor were the police informed of any data collected, including the alcohol concentration measured by our own digital alcohol breath analyzer. Subjects were not returned to the traffic police even when the alcohol was detected by our team.

After they had understood the purpose of the study they were asked for their interest and consent to participate of it. Drivers who refused to participate of this study were released with no charges. However, those subjects who gave informed consent and subsequently showed levels of alcohol above the legal limit according to Brazilian laws were instructed to not drive further, giving the vehicle to be driven by any other occupant that had not drunk or calling someone from their family or friends to come to get them.

After having been informed of all the procedures and giving written informed consent, drivers who agreed to participate in this survey were submitted to a brief interview (5 min) concerning some of their personal characteristics, without leaving the car.

Blood alcohol concentration

Following the interview, drivers who agreed were submitted to a digital alcohol breath analyzer (Alcomate—Digital Alcohol Detector, Model CA 2000—AK Solutions Inc.) to determine their BAC. Drivers were kept seated in their driver's seat while blowing the air into the alcohol breath analyzer. This procedure was very fast, taking approximately 1 min.

Frontal function assessment

After the BAC was determined, drivers who also agreed to a frontal function examination were conducted through a brief tool exploring different domains of executive function using the FAB, as described by Dubois et al. (2000). This battery consists of six subsets exploring the following: conceptualization (subjects have to conceptualize the links between two objects from the same category, e.g., an orange and a banana), mental flexibility (subjects need to recall as many words as they can beginning with a given letter in a 1-min trial), motor programming (subjects need to execute a motor series in a correct order), sensitivity to interference (subjects must provide an opposite response to the examiner's alternating signal), inhibitory control (subjects must inhibit a response that was previously given to the same stimulus), and environmental autonomy (subjects must inhibit the activation of patterns of behavior triggered by sensory stimulation, such as the prehensile behavior when they see the examiner's hand). Each of these subsets is scored from 0 (zero) to a maximum of 3. Therefore, the maximum total score of FAB would be 18.

Statistical analysis

Comparisons between any two categories, such as drivers without (BAC equal to zero) or with any alcohol (BAC equal or above 0.01%) in their blood, were performed using the two-sampled unpaired *t*-test.

A one-way analysis of variance (ANOVA) for independent measures followed by Fisher's Least Significant Difference (protected *t*-test) was used in the comparison between the FAB total scores and FAB subset scores among either three (BAC equal to zero, BAC between 0.01% and 0.05%, and BAC equal or above 0.06%) or five (BAC equal to zero, BAC between 0.01% and 0.05%, BAC between 0.06% and 0.15%, BAC between 0.16% and 0.25%, and BAC between 0.26% and 0.39%) categories.

An additional analysis of the variance of linear regression between the FAB scores was performed considering the mean (±S.E.) of the FAB total scores obtained in increasing order of alcohol concentration in the blood (five BAC categories).

A two-tailed α level of 0.05 was used to determine statistical significance. GB-Stat Professional Statistics & Graphics v. 6.5 (Dynamic Microsystems, Inc., Silver Spring, MD), GraphPad Prism 4.0 (GraphPad Software, Inc., San Diego, CA), and Statistical Package for Social Sciences (SPSS) software (SPSS, Inc., Chicago, IL) were used for statistical analysis and graphic presentations.

Results

Out of the 592 randomly recruited drivers, 17.2% (102 drivers) refused to voluntarily participate in this survey. Of the remaining individuals, 82.8% (490 drivers) answered the survey, 90.6% (444 drivers) allowed their BAC determined by a Digital Alcohol Breath Analyzer, and from these, 389 drivers (79.4%) had their frontal function assessed by the FAB.

Most of the 490 drivers were male (82.0%), with 214 drivers (43.7%) aged between 20 and 30 years and 128 drivers (26.1%) between 31 and 40 years. Consequently, this sample was mostly composed of young subjects (69.8% aged between 20 and 40 years). These drivers were mostly (66.7%) college graduates or graduate students in college, and 87.3% were employed in either formal or informal jobs.

According to Brazilian legislation, the maximum BAC allowed for drivers was 0.06% at the time these data were collected. Therefore, the results will be presented in categories considering no evidence of alcohol (BAC equal to zero), the presence of alcohol in a range described by Brazilian laws (BAC between 0.01% and 0.05%), and above the limit allowed by Brazilian laws (BAC equal or above 0.06%). Additional categories of BAC above 0.06% were also considered to provide a more detailed analysis of the results, and two simple categories such as absence (BAC equal to zero) or presence of alcohol (BAC equal or above 0.01%) were also included for more general analysis.

Thus, of the 444 drivers who agreed to this survey and also allowed their BAC measured, 62 drivers (14%) showed a BAC equal to or above 0.06%, and 46 drivers (10.4%) had BAC between 0.01% and 0.05%. In total, 108 drivers (24.4%, or approximately 1 in 4) presented alcohol in their blood when they were driving at night on streets or avenues with intense traffic.

From 444 drivers, the majority (n = 389) agreed to have their frontal function assessed by the FAB. Among the drivers with no alcohol in their blood (BAC equal to zero) (n = 293), the mean of the total score observed in the FAB was 14.2, whereas the mean of the total score achieved by the sample group with any amount of alcohol in their blood (BAC equal to or above 0.01%) was 13.2 ($n = 96$). The score obtained by drivers showing any amount of alcohol in their blood was significantly smaller ($t = 3.286$, df = 387, $P < .001$) as compared with drivers with no alcohol in their blood (Fig. 1A).

Considering the categories of BAC in accordance with Brazilian legislation, the means of the FAB total score in the group with a BAC between 0.01% and 0.05% and equal or above 0.06% were 13.5 ($n = 39$) and 13.0 ($n = 57$), respectively (Fig. 1B). There were statistically significant differences among these categories ($F[2, 386] = 5.89$, $P = .003$).

The mean of the FAB total scores obtained by drivers with a BAC equal or above 0.06% was significantly smaller ($P < .01$) compared with drivers with no alcohol (BAC equal to zero) in their blood (Fig. 1B). Although statistically insignificant, it is interesting to note that even within concentrations allowed by Brazilian laws (between 0.01% and 0.05%), the mean of the FAB total scores was smaller compared with drivers with no alcohol in their blood.

In a more detailed analysis examining expanded categories of BAC (Fig. 1C), the disruptive effect of alcohol was shown to be progressively worse at higher BACs ($F[4, 384] = 3.94$, $P = .0038$). Drivers with a BAC between 0.16% and 0.25% or 0.26% and 0.39% showed statistically significantly smaller ($P < .05$ or $P < .01$, respectively) FAB total scores compared with drivers with no alcohol in their blood (Fig. 1C). The FAB total scores of drivers showing the highest concentration of alcohol (0.26–0.39%) was also significantly lower ($P < .05$) than those of drivers with lower levels of alcohol (0.01–0.05% or 0.06–0.15%). Linear regression analysis showed a significant decrease in FAB scores with increasing levels of BAC ($Y = 14.3 - 0.6X$; $r = -0.86$; $F[1, 3] = 19.2$, $P = .02$) (Fig. 2).

An additional analysis considering the subsets of FAB according to Dubois et al. (2000), that is, conceptualization, mental flexibility, motor programming, sensitivity to interference, inhibitory control, and environmental autonomy, was carried out across different categories of BAC, in accordance with Brazilian laws (Table 1). Of the mentioned subsets, motor programming was shown to be the most alcohol impaired frontal function, with significant decreases in function, especially when drivers presented BAC equal or above 0.06% ($P < .01$), compared with drivers with a BAC equal to zero (Table 1).

In examining the frontal function under the effects of alcohol, the FAB total scores were shown to be smaller across all the age ranges (Fig. 3A). In particular, young adult drivers, aged between 20 and 30 years, were the most affected. The mean of the FAB total scores in young adult drivers with a BAC equal or above 0.01% was significantly ($t = 2.59$, df = 168, $P = .01$) smaller compared with drivers within the same age group with no alcohol in the blood (BAC equal to zero) (Fig. 3A, left panel).

In an expanded analysis of this age range (Fig. 3B), there was a statistically significant difference among BAC categories ($F[4, 165] = 3.11$, $P = .017$). Those who had a high concentration of alcohol in the blood (BAC between 0.26% and 0.39%) showed a significantly lower ($P < .01$) FAB total score than young drivers with either no alcohol in their blood (BAC equal to zero) or with a BAC between 0.06% and 0.15% ($P < .05$). Comparisons between these categories in other age ranges were not statistically significant (data not shown).

We mentioned above that most of the subjects of the total sample (66.7%, $n = 490$) graduated from college or were graduate student in college. By examining the relationship between schooling and FAB performance in the group of subjects with no alcohol in their blood (BAC equal to zero, $n = 293$), we found that the mean FAB total score (±S.E.) was higher with the increasing level of education (primary school: 9.67 ± 0.62 [$n = 13$]; high school: 13.28 ± 0.27 [$n = 72$]; student in college: 14.68 ± 0.26

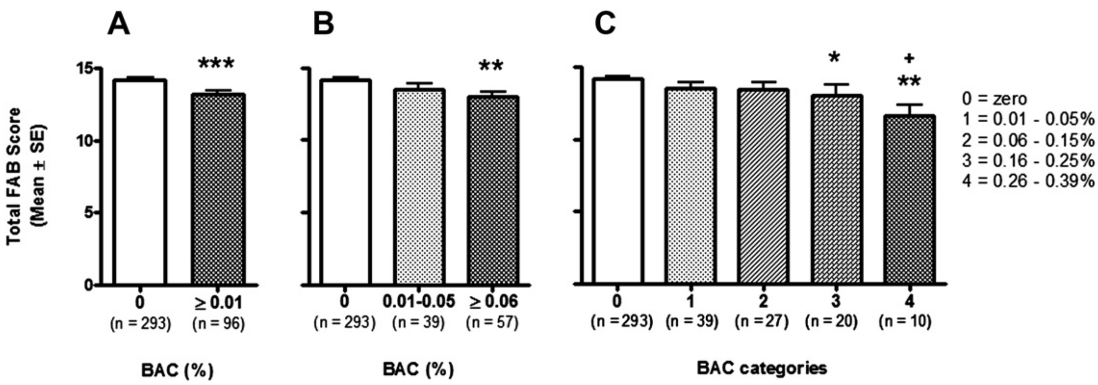

Fig. 1. Mean (±S.E.) of the frontal assessment battery (FAB) total scores of nocturnal drivers in streets and avenues with intense traffic in a Brazilian city, according to different categories of blood alcohol concentration (BAC): (A) no alcohol (BAC equal to zero) or presence of alcohol in the blood (BAC equal or above 0.01%); (B) no alcohol (BAC equal to zero), BAC between 0.01% and 0.05%, and BAC equal or above 0.06%; (C) 0 = no alcohol (BAC equal to zero), 1 = BAC between 0.01% and 0.05%, 2 = BAC between 0.06% and 0.15%, 3 = BAC between 0.16% and 0.25%, and 4 = BAC between 0.26% and 0.39%. *$P < .05$, **$P < .01$, and ***$P < .001$ as compared with drivers with no alcohol in their blood (BAC equal to zero); $^{+}P < .05$ as compared with drivers with BAC between 0.01% and 0.05% or 0.06% and 0.15%.

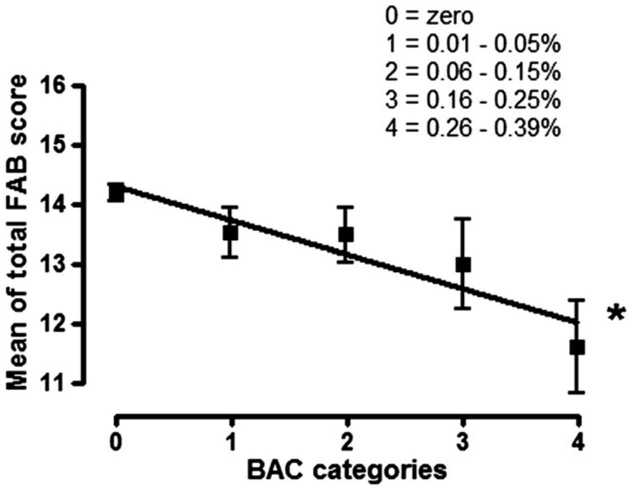

Fig. 2. Linear regression analysis of the mean total performance of the frontal assessment battery (FAB) in nocturnal drivers in streets and avenues with intense traffic in Brazilian city, according to different categories of blood alcohol concentration (BAC) considering 0 = no alcohol (BAC equal to zero), 1 = BAC between 0.01% and 0.05%, 2 = BAC between 0.06% and 0.15%, 3 = BAC between 0.16% and 0.25%, and 4 = BAC between 0.26% and 0.39%. *$P < .05$; ANOVA for linear regression analysis.

[$n = 62$]; college graduates: 14.80 ± 0.19 [$n = 146$]). This suggests that the level of education influenced the FAB performance ($F[2, 288] = 24.44$, $P < .0001$). Subjects with primary school level showed mean FAB total score significantly lower ($P < .01$) than subjects with high school, who in turn had significantly lower FAB total scores ($P < .01$) than college students and college graduates. We also examined the influence of age on FAB performance and found that young subjects showed a significantly ($F[4, 288] = 5.36$, $P = .0004$) higher mean FAB total score than older subjects (18–19 years old = 15.43 ± 0.30 [$n = 7$]; 20–30 years old = 14.85 ± 0.21 [$n = 130$]; 31–40 years old = 13.70 ± 0.28 [$n = 76$]; 41–50 years old = 13.41 ± 0.33 [$n = 58$]; above 51 years old = 13.64 ± 0.65 [$n = 22$]). Subjects in the range between 20 and 30 years of age showed a higher mean FAB total score than subjects between 31 and 40, 41 and 50 ($P < .01$), and above 50 years of age ($P < .05$).

Thus, an additional analysis was conducted considering the FAB performance of young subjects (20–30 years old) with high educational level (students in college and graduated from college) under different categories of BAC. We found that even with high school degree these young subjects were still significantly impaired in their frontal function when examined under the influence of alcohol. Young subjects (20–30 years old) with alcohol blood levels equal to or greater than 0.01% ($n = 29$) showed a lower ($t = 2.414$, df = 13, $P = .017$) mean FAB total score (14.21 ± 0.49) than young subjects with no detectable alcohol in their blood ($n = 104$, mean FAB total score equal to 15.33 ± 0.20). Consistent with the results presented for the total sample, there was a statistically significant difference in the FAB total scores among the three categories of BAC ($F[2, 130] = 3.24$, $P = .04$), and the young subjects with BAC equal to or greater than 0.06% showed a lower mean FAB total score ($P < .05$) than young subjects with no alcohol in their blood (BAC equal to zero: 15.33 ± 0.20, BAC between 0.01% and 0.05%: 14.64 ± 0.77, and BAC equal or above 0.06%: 13.94 ± 0.64).

Discussion

In this study, measures of BAC by a portable digital breath alcohol analyzer showed a high frequency (24.4%) of alcohol consumption in participating individuals who were driving of streets with a high level of traffic at night in the city of Vitoria, Brazil. A worrying result was that the majority of these subjects with alcohol in their blood were young adult male drivers. Unfortunately, this only provides further evidence of the high-risk behavior characteristic of the youth, and their subsequent involvement in alcohol-related traffic crashes that result in premature death or severe disability.

Although these data were not surprising, the most important observation of the present study was reduced frontal function in subjects presenting with alcohol in their blood, especially in moderate to high concentrations.

The brief battery for frontal function assessment (FAB) used in the present study was easily applied in those drivers who agreed to have their frontal function examined. The simple analysis showed that the presence of alcohol in the blood was enough to significantly reduce frontal functions. This reduction was statistically significant in subjects

Table 1
Subsets of frontal assessment battery (FAB) in nocturnal drivers in streets and avenues with intense traffic in Vitória of Espírito Santo, a Brazilian city, according to three different categories of blood alcohol concentration (BAC) determined by a Digital Alcohol Breath Analyzer

	Categories of BAC		
Subsets of FAB (mean ± S.E.)	0 (zero) ($n = 293$)	0.01–0.05% ($n = 39$)	≥0.06% ($n = 57$)
Conceptualization	1.48 ± 0.06	1.21 ± 0.18	1.32 ± 0.15
Mental flexibility	2.51 ± 0.04	2.51 ± 0.10	2.39 ± 0.09
Motor programming	2.17 ± 0.06	2.10 ± 0.16	1.68 ± 0.14**,+
Sensitivity to interference	2.64 ± 0.04	2.49 ± 0.13	2.63 ± 0.07
Inhibitory control	2.50 ± 0.05	2.31 ± 0.16	2.25 ± 0.13
Environmental autonomy	2.88 ± 0.03	2.90 ± 0.07	2.79 ± 0.08

**$P < .01$ as compared with BAC 0 (zero). +$P < .05$ as compared with BAC 0.01–0.05%.

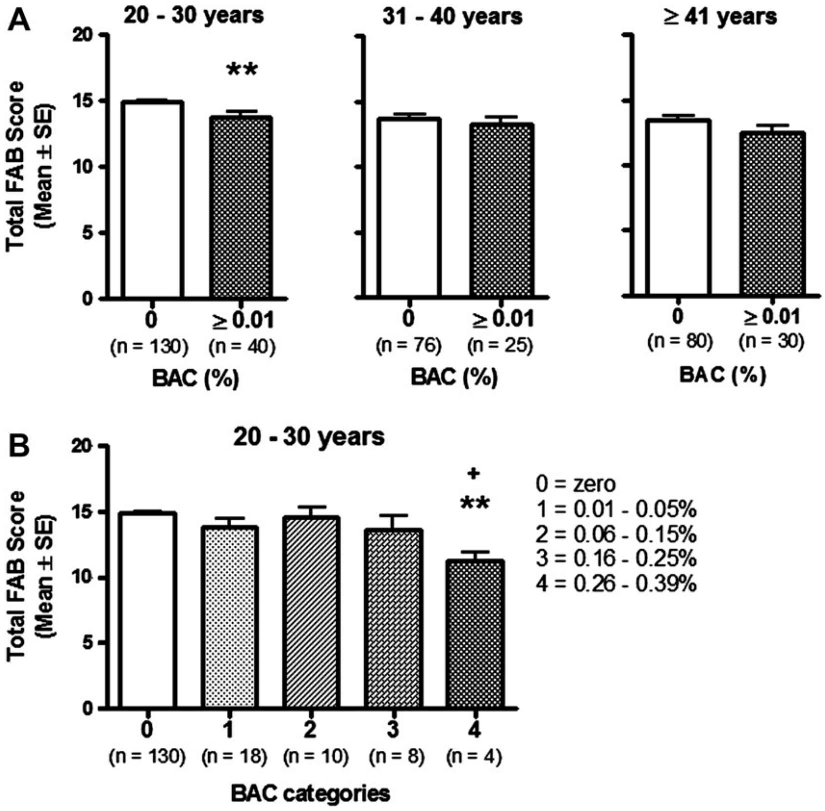

Fig. 3. Mean (±S.E.) of the frontal assessment battery (FAB) total scores of nocturnal drivers in streets and avenues with intense traffic in a Brazilian city, considering two different categories of blood alcohol concentration (BAC): no alcohol (BAC equal to zero) or presence of alcohol in the blood (BAC equal or above 0.01%), in different age ranges: 20–30 years old (left panel), 31–40 years old (middle panel), and equal and above 41 years old (right panel) is shown in A. An analysis considering five categories of BAC: 0 = no alcohol (BAC equal to zero), 1 = BAC between 0.01% and 0.05%, 2 = BAC between 0.06% and 0.15%, 3 = BAC between 0.16% and 0.25%, and 4 = BAC between 0.26% and 0.39% in young drivers (20–30 years old) is shown in B. $^{**}P < .01$ as compared with drivers with no alcohol in their blood (BAC equal to zero); $^{+}P < .05$ as compared with drivers with BAC between 0.06% and 0.15%.

presenting a BAC equal to or greater than 0.06%. However, it is important to note that even subjects with low BACs (between 0.01% and 0.05%) had smaller FAB total scores. The reduction of the FAB total score was substantial in those who had high BACs (above 0.15%) and even more pronounced for those with very high (above 0.26%) BACs.

These results showed a significant inverse relationship between BAC and frontal function, where a higher BAC corresponded to a lower FAB score, demonstrating the progressive decrease in frontal function with increasing concentrations of alcohol. It is important to note that the progressive reduction in the FAB total score with increasing concentration of alcohol in the blood was evident even considering that the mean FAB total score of subjects with no alcohol in their body was already low, probably because of the uncontrolled environmental condition during the task application. However, it should be considered that all the subjects were examined in a very similar way, during the same time window, and were compared within the same conditions.

Ogden and Moskowitz (2004), reviewing studies from the last 50 years, concluded that there was no evidence of a threshold blood alcohol below which impairment does not occur and that there was no defined category of drivers who will not be impaired by alcohol. They point out that those studies examining the effects of alcohol on more complex tasks, such as divided attention and mental workload, showed a significant impairment at very low BACs (<0.02 g/100 mL) (Ogden and Moskowitz, 2004). Although the level of impairment was not statistically significant, this observation is not without merit, as the present study also indicates a reduction of frontal executive functioning for subjects presenting even low concentrations of alcohol in their blood.

According to the National Highway Traffic Safety Administration (2005), a motor vehicle crash is considered to be alcohol related if at least one driver or nonoccupant (such as pedestrian or cyclist) involved in the crash is found to have had a BAC of 0.01 g/dL or higher, although the term ''alcohol related'' does not necessarily mean that a crash or fatality was caused by the presence of alcohol. The present study showed the simple evidence that a BAC above 0.01% was enough to be related to a decrease in frontal executive function, which may suggest that ''alcohol-related'' crashes or fatalities could be in fact because of the presence of alcohol, even in small amounts.

Blomberg et al. (2005) conducted a case–control study examining the relative crash risk associated with drivers'

BAC levels. One of main results reported by these authors was that a statistically significant increase in crash risk began at 0.04% BAC. They also found small but statistically insignificant increases in relative risk between 0.01% and 0.03% BACs, and the direction of change was consistent with a monotonically increasing crash risk beginning at BACs close to zero (Blomberg et al., 2005). This evidence suggests that alcohol may be related to increased crash risk, even in small amounts, and the present study adds executive dysfunction caused by alcohol as also being partly involved in this condition.

In a specific analysis of the subsets of FAB, it was observed that the most compromised frontal function was related to motor programming. Motor programming is required for temporal organization, maintenance, and execution of successive actions (see Dubois et al., 2000), and these operations can be tested by asking the subject to execute motor series in specific orders.

In this specific subset of FAB (Dubois et al., 2000), subjects were first asked to look carefully a simple sequence of Luria's (1966) motor series, such as ''fist-palm-edge,'' performed three times by the examiner with a left hand. Then, they were asked to perform these movements with their right hand three times, first with the examiner and then alone. According to Dubois et al. (2000), they had 3 as a maximum score if they performed six correct consecutive series alone, 2 if they performed at least three correct consecutive series alone, 1 if they failed to perform alone, but performed three correct consecutive series with the examiner, and 0 if they could not perform three consecutive series even with the examiner. In the present study, the mean of the motor programming score was significantly lower in subjects with a BAC equal to or greater than 0.06% than the scores for subjects with a BAC of either 0% or between 0.01% and 0.05%. In fact, 70% of the subjects with a BAC of 0% and 69% of the subjects with a BAC between 0.01% and 0.05% showed scores between 2 and 3, respectively, whereas more than half (51.6%) of the subjects with a BAC equal or above 0.06% presented scores between 0 and 1, showing that alcohol significantly compromised this frontal function.

The measurement of motor programming function, such as Luria's (1966) ''fist-edge-palm'' task, assesses the ability to learn novel motor sequences and to engage in purposeful motor output (Suchy and Kraybill, 2007). Suchy and Kraybill (2007) showed that measures of motor programming tasks are very well correlated with performances on measures of executive functioning, suggesting that motor programming tasks should be included in batteries assessing executive functioning.

Executive functions refer to high-order functions operating in nonroutine situations, such as novel, conflicting, or complex tasks (Godefroy, 2003). They are necessary for goal-directed behavior, including initiating and stopping a finished action or task, monitoring and changing behavior as needed, and planning future behavior when faced with novel tasks and situations. These cognitive functions allow us to anticipate outcomes and adapt our responses to changing situations. As a result, such abilities are extremely important during automobile driving, and driving may become unsafe if executive functions are blunted in one or more of its components.

According to Barkley and Cox (2007), human factors are considered to be the most common cause of automobile accidents, including actions taken by or the condition of the driver, such as speeding, violating traffic laws, drug or alcohol use, errors in decision making, age, and inattention.

Converging evidence from postmortem, electrophysiological, cerebral glucose-metabolism, and in vivo high-resolution structural magnetic resonance images studies (Sowell et al., 1999) shows a relatively late frontal maturation. Sowell et al. (1999) showed continued temporal and spatial progressive maturation into the frontal lobes in young adults, aged between 23 and 30 years, highlighting the potential importance of frontal/striatal maturation to adult cognition. Over this age range, the delayed structural maturation of the frontal lobes converges to a continued development of cognitive functions attributed to these structures (Sowell et al., 1999).

Our results are consistent with this delayed maturation in frontal executive function. It is likely that the age-related delay in frontal executive function maturation makes younger individuals more vulnerable to the disruptive effects of alcohol on executive function.

In summary, the present study showed that about 25% of the night drives in a Brazilian city were driving after consuming an alcoholic beverage. The presence of alcohol in increasing concentrations was significantly correlated with a decrease in executive frontal function, specifically on motor programming functions, especially in young adults between 20 and 30 years of age.

The higher vulnerability of young adults to the disruptive effects of alcohol on frontal functions and the ongoing maturing process of frontal lobe structure and function may constitute converging factors highly related to the worldwide evidence of high-risk involvement of the youth in automobile crashes. The effects of alcohol on young adults need to be more carefully examined by cognitive studies, and more direct preventive solutions should be focused on this age group.

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