ABSTRACT. Objective: To assess the effects of acute alcohol intoxication on lateralized readiness potential (LRP), a central measure of movement-related brain activity, and the potential association of such effects with personality measures. Method: Male volunteers (N = 12) alternated responding hands during a "go/no-go" verbal recognition task across all four sessions of the balanced placebo design in which beverage content (either juice only or a vodka and juice mixture that raised the average blood alcohol concentration to 0.04%) was crossed with instructions as beverage content. Results: Whereas the instructions had no effect on behavioral (response accuracy and reaction time) and physiological (LRP) measures, alcohol decreased reaction times adjusted for psychomotor speed. As expected, large LRP's were recorded on "go" trials and were not affected by the beverage. However, the "no-go" word trials did not require and did not evoke motor responses, also evoked significant LRP's under alcohol but not placebo. Since only trials with correct responses and correct omissions from responses were included in the averages, the motor preparation was not completed and was terminated before the motor response on "no-go" trials. Similarly, there was a decrease in spectral power of the movement-related mu rhythm as "no-go" trials under alcohol. Conclusion: Alcohol may result in disinhibition such that the "response execution" process is activated based on very preliminary stimulus evaluation. This alcohol-induced brain activity signaling premature motor preparation exhibited correlation trends with personality traits related to impulsivity hyperactivity and antisocial tendencies, thus concuring with other evidence that indicates commotions between alcoholism and impulsivity, disinhibition and antisocial behavior. The LRP on "no-go" trials could potentially be used as a psychological index of the impulsive tendencies induced by alcohol intoxication. (J Stud Alcohol 61: 24-37, 2000)

HIGH INCIDENCE of alcohol intoxication associated with violent crimes (Collins, 1981) has led to hypotheses about alcohol-induced aggression. Laboratory research on aggressive behavior indicates that intoxication indeed increases the likelihood of aggression (Bushman and Cooper, 1990) and that it interacts with the level of provocation (Gustafson, 1993), cognitive functions of the frontal lobes (Lau et al., 1995), dose (Chermack and Taylor, 1995) and gender (Giancola and Zeichner, 1995). However, the relationship between alcohol and aggression is not straightforward. Behavioral acts that may be labeled as aggressive are remarkably varied and include such aspects as impulsivity, disinhibition, social inappropriateness, impaired thought processes and lack of sexual restraint. In spite of correlational evidence linking alcohol and aggression to neurochemical changes in humans (Virkkunen and Linnola, 1993), direct physiological evidence of alcohol effects on impulsivity as an aspect of aggression is missing. In a behavioral study, Parsons et al. (1972) reported that chronic alcoholics were unable to suppress fast responding in a task that required slow motor control, suggesting more hasty or impulsive motor behavior. A closer scrutiny of the effects of alcohol on the preparation for motor responses may elucidate the physiological basis of impulsive acts. The lateralized readiness potential (LRP), a central measure of brain activity related to the preparation to move, may potentially serve as an index of impulsive motor behavior. In tasks requiring an overt response, LRP is a measure of the motor-planning aspect of the stimulus processing which occurs concurrently with stimulus presentation, evaluation and integration. A negative scalp potential recorded contralaterally to the responding hand (Rothbaum et al., 1976) is thought to be a later part of the slow negative readiness potential (Bereitschaftspotential) that precedes voluntary movement (Deecke, 1987; Shibasaki et al., 1980). It is primarily generated in precentral and premotor cortices as suggested by intracranial recordings (Hugl et al., 1994; Reber et al., 1992; Rektor et al., 1994). A measure of lateralization of this potential that is obtained by subtracting the ERP recorded over motor/premotor cortex (contralaterally to the responding hand from the ERP recorded contralaterally to the responding hand. Subsequently, the LRP's of both hands are averaged
together (Coles, 1989). This procedure permits inspection of movement-related potentials since it eliminates other activity that is unrelated to motor response. Although the LRP has been utilized in many studies and considerable evidence exists on its evoking and modulating parameters, the effects of alcohol on the LRP have not previously been investigated.

In order to provide an assessment of the motor-related cortical activity in a manner complementary to the LRP, the EEG data were also submitted to the analysis of spectral power in frequency domain. Rhythmic oscillations around 10 to 20 Hz localized in the Rolandic cortex (mu-rhythm) are considered to indicate an "sifting" state of the sensory-motor cortex and are transiently suppressed by motor planning and movements, predominantly contralateral to the movement (Charlat, 1976) in a manner specific to the somatic cortical representation of the moving body part (Amyo et al., 1993; Pfurtscheller et al., 1997). The same procedure used to derive the LRPCs in the time domain was also applied in the frequency domain, resulting in the lateralized event-related spectral power (LERSP).

The purpose of this study was to determine the effects of moderately low level acute intoxication on the LRP (obtained in the time domain) and the LERSPs (obtained in the frequency domain) as central indices of motor response preparation, as well as to assess their potential association with personality measures. The results reported here are a portion of a comprehensive study investigating effects of alcohol on physiological indices of higher cognitive functions. Detailed descriptions of other tasks will be reported elsewhere.

Method

Subjects

Twelve healthy, right-handed, nonsmoking men (mean ± SD age = 23.5 ± 2.3 years) completed all four sessions of the experiment. They were all social drinkers, native speakers of English and reported no medical condition, illicit drug use or excessive drinking. The participants reported no alcohol abuse in their families.

Design

Each subject participated in all four sessions of a balanced placebo design obtained by crossing the factors of beverage and instruction to the beverage context ("expectancy") as: (1) given alcohol, told alcohol (GAT); (2) given alcohol, told juice (GATJ); (3) given juice, told alcohol (GJTA); (4) given juice, told juice (GJTI). Except for the consumed beverage and information concerning the beverage content, the same protocol was followed in each recording session.

In order to minimize the potential effects of variability in alcohol metabolism and circadian rhythms, the recording sessions started between 3 and 4 pm and were scheduled at least 2 days apart. Subjects were asked to abstain from food for 3 hours and from alcohol for 24 hours prior to each experimental session. In addition to the verbal recognition task, the protocol included a simple one discrimination and a mood-rating questionnaire. The mean alcohol concentrations (BACs) were monitored throughout the experiment with an Alco-sensor III breath analyzer (Intoximeters, Inc., St. Louis, MO). On average, the verbal memory task was administered 72 minutes after the drink presentation, just after the participants reached a peak BAC (0.045%); the measures taken before and after the task showed BACs of 0.045% and 0.044%, respectively. At the end of each experimental session the subjects rated the task difficulty, the beverage content, self-perceived level and latency to maximum of intoxication. They remained in the laboratory until their BAC diminished to negligible (i.e., below 0.015%) levels.

Prior to the beginning of the study, the subjects were informed in writing that they would consume alcohol or a placebo and that the information given to them regarding the beverage content might be inaccurate. The written consent was approved by the appropriate institutional human subject protection committees. Upon completion of the experiment the participants were asked about their suspicions regarding deception. They were debriefed and the exact design and purpose of the study were explained in detail.

All participants were in an introductory recording session prior to the first experimental session. During this session they were familiarized with the laboratory setting and with the recording procedure. In addition, they filled out the following questionnaires: Michigan Alcoholism Screening Test (MAST; Selzer, 1971); Alcohol Use Questionnaire (AUQ) adapted from Mills et al. (1983); Childhood Hyperactivity Questionnaire (HKMB; Tarter et al., 1977); Eysenck Personality Questionnaire (EPQ; Eysenck and Eysenck, 1975); Socialization Scale (SSQ) of the California Psychological Inventory (Gough, 1960).

Beverage administration

Results of a pilot study conducted prior to the experiment suggested that 0.4 g of 100% ethanol per kg of body weight, Smirnoff vodka 40% alcohol, mixed with chilled grapefruit juice and pineapple-orange-guava frozen concentrate in a 1:5.5 ratio, successfully disguised the taste of alcohol. The beverage administration procedure was adapted from Rehband and Marfati (1981) and included the cues (e.g., vodka bottle) appropriate to the instructional "expectancy" condition. In both "told alcohol" conditions a remeasured amount of either vodka (to GAT) or water (in GJTA condition) was poured from a Smirnoff vodka bottle and mixed, in subject's view, with the juice glass in a glass pitcher. In the GJTA condition strong aftertaste cues were provided by a 0.2 piece of vodka-saturated gauze placed in the cap of the bottle underneath to the subjects.
Task

Subjects were instructed to memorize a list of 20 words that were exposed for 100 msec at a rate of one word every 4 seconds. The words were presented individually at the center of a black and white computer-driven 24" TV screen within a visual window subtending an angle of 3.5°. At all other times, a fixation target consisting of five star characters was shown as the same screen location. In the recognition task that followed, 10 words from the initially memorized list were randomly chosen as "target" words and were presented on half of the total of 200 trials, mixed in among the new unlearned words. Subjects were instructed to press a microswitch every time one of the originally memorized words appeared on the screen. Reponding hands alternated semi-randomly between the sessions. A feedback tone (sawtooth waveform), 100 msec duration, occurred 1500 msec after word onset informing the subjects whether their response was correct (high pitch = 500 Hz) or not (low pitch = 100 Hz). All the words were four to five letters long, equated across lists on their imagery, concreteness and frequency of occurrence as the basis of published norms (Francis and Kucera, 1962; Paivio et al., 1968). The words had low frequency of occurrence (one to seven per million) and were presented in a random order. A different set of words was used in each session in a randomized manner.

The task difficulty ratings obtained on a 1-5 Likert scale at the end of each experimental session indicated that the task was perceived to be very moderately easy (mean r = 1.71 ± 0.87). The ratings were not influenced by the factor of beverage or instructions nor did they become progressively easier or more difficult across the recording sessions.

Recording of event-related potentials

The electroencephalogram (EEG) was recorded with a lys- cra fitted electrode cap (Electro-Cap International, Inc., Eaton, OH) from 13 scalp sites: Fz, Cz, Pz, F3, F4, P7, P8, C3, C4, P3, P4, T5, T6. Of the 10-20 International system, an electrode placed on the tip of the nose served as the reference and one on the right earlobe as ground. The electrooculogram (EOG) was recorded with bipolarly referred electrodes placed at the outer canthus of the right eye and just above the nasion. The electrode impedance was kept below 5 kOhms. The EEG and EOG were recorded with a Grass 16-channel polygraph with DC amplifiers set at 0.5 sec time constant and with a bandwidth of 0.05 to 75 Hz (1/2 amplitude). EEG and EOG data for each trial were digitized at a rate of 200 Hz (5 msec per point) with 12-bit accuracy and stored on an IBM-PC compatible computer for off-line analysis. EEG data sampling began 100 msec before each word onset and continued for 2600 msec.

Results

Behavioral measures

Repeated measures ANOVAs were performed on the data of 11 subjects, as the behavioral data of one subject were not available for all four sessions. The analysis revealed no significant effects of beverage, instructions, hand or session order on the reaction time (RT) averaged across trials with correct responses. On average (±SD), the subjects responded 641± 68.5 msec after stimulus presentation onset. Recognition performance was nearly perfect with 98.3% ± 1.8 mean correct responses and was not affected by any of the factors.

In addition to the verbal memory task, the subjects performed a simple tone discrimination task—an "oddball" paradigm with easily discriminable frequent nontarget, rare target and rare deviant tones. Subjects were instructed to press a button upon detection of the target tone. RTs obtained in this nondemanding paradigm probably reflect the speed of simpler psychomotor processes. In contrast, the verbal task requires involvement of more complex word memory processes, resulting in longer reaction times. It can be hypothesized that the difference in RT between the two tasks may be due to activation of the higher brain functions related to verbal perception and memory when they are corrected for psychomotor speed. In order to test this hypothesis, a within-subject ANOVA was performed on the difference scores obtained by subtracting RTs in tone discrimination from RTs in the verbal memory task for each of 11 subjects.

Although there were no beverage effects on RT in either task when analyzed separately, the difference RTs were affected by the type of beverage (F = 9.23, 10,1df, p < .05). In alcohol conditions, the average RT difference between two tasks was only 14.6 msec. When given juice, the difference was 77.9 msec. This result appears to be caused by a decrease in RTs in the word task when alcohol was consumed (Figure 1). It seems that in the verbal memory task the subjects reacted more hastily and, perhaps, more impulsively when given alcohol than when given juice. The beverage effect in the word task per se was not significant (F = 2.03, 10,1df, p = .18).

Lateralized readiness potentials (LRP)

All trials in which incorrect responses were made, or in which eyeblinks or other artifacts occurred, were eliminated from the analyses. The overall mean (±SD) number of trials retained in averages of new and repeated words was 90.8 ± 5.1 and 91.2 ± 6.9, respectively. Average waveforms were obtained for each level of the within-subject factors: task condition (new and repeated words), beverage (given juice or alcohol), responding hand (left and right) and for each electrode site.
An investigation of the bilateral LRPs was permitted by counterbalancing the responding hand across sessions. However, the factors of beverage and responding hand were not orthogonal for three subjects. Consequently, the analyses were performed for nine subjects for whom the two levels of the beverage factor were crossed with both responding hands. The movement-related LRPs were obtained by a two-step procedure (Coles, 1989): (1) averaged scalp potentials recorded over Rolandic areas ipsilaterally to the responding hand were subtracted from the contralateral potentials (e.g., C3-C4 for right-hand responding); (2) the subtracted lateralized measures obtained for left and right hands were averaged together.

The LRP was quantified by measuring average voltage over C3 and C4 within the latency window 100-600 ms post-stimulus onset in 100 ms increments. All measures were expressed in microvolts (amplitudes) and milliseconds (latencies) with respect to a baseline period of 100 ms before stimulus onset. Repeated measures ANOVAs with factors—beverage (GA, GJ; stimulus (new vs repeat) and responding hand (left, right)—were performed on all of the average voltage measures obtained over C3 and C4. Since there were no effects of the instructions as to the beverage content, the data were summed across the factor of instructions.

Average LRPs obtained for trials in which the subjects responded correctly to repeated target words, or correctly withheld a response to non-target novel words, are presented in Figure 2 with superimposed potentials obtained in alcohol and placebo conditions. The movement-related negativity starts earlier and appears to be larger when alcohol was imbibed, as compared to placebo, for both target and novel words. Indeed, the main effect of beverage becomes significant in the 400-500 ms latency range (F = 6.1, 1/8 df, p < .05). A closer look at these effects reveals that the main effect is due to the alcohol-placebo difference on novel, non-target trials. The effect of beverage on the target trials does not reach significance in any of the examined latency windows. In contrast, the novel words consistently evoked a larger negativity in alcohol condition, as compared to placebo, in 200-500 ms range (F = 10.2, 1/8 df, p < .05).

A decision whether to press a button or not could be made only after the appropriate level of semantic and thematic analysis was reached. Target "go" words required a motor response, and a large bilateral movement-related negative potential indexing preparatory brain activity can be observed in Figure 2a. This negativity preceding the response did not differ significantly between the alcohol and juice conditions. Since the novel "no-go" words did not require a response, no movement-related activity was necessary. Consistent with such a requirement, novel words did not evoke any negativity in the placebo condition. In contrast, mild inebriation resulted in a motor preparation for a response on "no-go" trials.
In addition to analyzing the movement-related potentials in time domain, the same data were submitted to the analysis of spectral power in frequency domain in order to assess the task and beverage effects on the Rolandic mu-rhythm. Spectral power was measured with discrete Fourier transform applied to EEG epochs from individual trials and spectral averages were obtained for each subject and for each condition. The same general procedure used for obtaining the LRP (in time domain) was followed for LERSP (in frequency domain). For the purposes of statistical analysis, LERSP was measured as the square root of power and baseline-normalized at the peak of the power spectrum that fell within the range of mu, at the frequency of 15 Hz (12.5 to 17.5 Hz range). The power spectra were obtained for two time windows: 200-450 msec and 400-600 msec post stimulus onset and analyzed with 2 × 2 ANOVAs with the factors of repetition (new and repeated trials) and beverage (alcohol and juice) (Figure 3).

Within the 200-450 msec time window, LERSP decreased to the new words in the alcohol condition (F = 7.6, 1/8 df, p < .05) as compared to placebo. A similar result was obtained for the 400-600 msec time window (F = 11.7, 1/8 df, p < .01). No effect of beverage was observed for the repeated words. These effects of alcohol mirror the results obtained on LRP's in time domain as a larger mu-rhythm decrease in LERSP was observed under alcohol on "no go" trials. Given that interruption of the mu-rhythm indicates motor preparation (Chatarri, 1976), this provides further evidence for an alcohol-evoked readiness to prematurely engage his motor-response system.

Personality and LRP

Based on reports of significant correlation between impulsivity and drinking problems (Nagoshi et al., 1991; Regier et al., 1990), an attempt was made to analyze the present data in a similar manner by examining the interdependence between the alcohol-related difference in LRP on the "no go" trials (a potential physiological index of impulsivity) and personality measures available on the same subjects. Pearson correlation coefficients were calculated between the alcohol-related LRP difference (obtained by subtracting the average LRP in juice from the average LRP recorded in alcohol conditions) and the following personality indices: the three dimensions of the Eysenck Personality Questionnaire (psychoticism, extraversion, neuroticism), the socialization index (SSQ) and childhood hyperactivity (HKMBD). Due to its small size, this data set is not well suited for the correlation approach as both physiological and personality questionnaire-type measures of impulsivity were observed. Bonferroni corrected (Bonf. p) probability values were obtained by multiplying the uncorrected p value by 5 (5 personality scales). Individuals who exhibited a larger alcohol-induced average LRP to novel ("no go") words within 100-200 msec latency had higher scores on the childhood hyperactivity (HK/MBD) scale (r = .77, p < .026, Bonf. p < .1). In addition, the alcohol-related LRP differ-

![Figure 3](image_url)
ence was positively correlated with psychotomia (r = 0.84, p < 0.01, Bonf. p < 0.05) and childhood hyperactivity (HKAHD: r = 0.66 p < 0.07, Bonf. p < 0.05), and negatively with socialization (r = -0.8, p < 0.017, Bonf. p < 0.05). The measure of lateralized spectral power exhibited a trend toward a correlation with the socialization scale (r = 0.68, p < 0.06, Bonf. r > 0.3). Although most of these correlations were rendered insignificant by a Bonferroni correction for multiple comparisons due to very low power, the r values indicate that these personality traits related to impulsivity shared about 60% or more of the variance with the alcohol-induced LRP on "no go" trials.

Discussion
Lateralized Readiness Potential is an electrophysiological index of asymmetry primarily related to the activation of pre-central and premotor cortices contralateral to the side of the movement. The LRP is derived by averaging the movement-related asymmetries for the two hands, thus eliminating any activity unrelated to the side of the movement. It has been re- 

tabulated that a large LRP develops on "go" trials accompa-
nied by an overt motor response (Coles et al., 1988). 

However, LRP has also been recorded on "no go" trials (Smith et al., 1995), even without any concomitantly recorded muscular activation (Oman et al., 1992). The LRP deriv-
a tion obtained in the present study during a simple verbal recognition task predictably showed a large movement-re-

lated negativity on target "go" trials. This motor-related potential did not differ significantly between the juice and al-
coh ol conditions. No LRP was observed to novel "no go" words in the juice condition. However, alcohol inebriation 

resulted in an LRP recorded on novel, untargeted "no go" tri-
aIs that peaked, on average, at 200 msec after stimulus onset and then returned to baseline. The LRP's were based on the artifactual-free trials in which the subjects correctly re- 

sponded to target words and correctly withheld responses to novel words. Nevertheless, a hand-specific motor prepara-
tion was initiated and was correctly terminated when alcohol was imbibed even in those trials that did not require and did not elicit overt responses. Clearly, in this "go/no go" situa-
tion, an appropriate initiation of a motor response should not start before a word stimulus has been analyzed sufficiently as to ascertain whether it's a target requiring a response, or it is a novel word signifying a response inhibition. Accordingly, no response preparation to novel "no go" words was initiated in juice condition. Yet, in the alcohol condition, the word presentation itself, rather than its completed analysis, trig-
erg a motor preparatory sequence. Since the responding hand was held constant throughout each recording session it is likely that the responding mechanisms were primed even before the onset of a stimulus (Gratton et al., 1988) and that

The LRP's on "no go" trials were elicited automatically, upon a stimulus detection in the alcohol condition. Thus, the data suggest an inappropriate premature response preparation based on insufficient and preliminary stimulus analysis (Osm-
an et al., 1993) which may be indicative of impulsive and hasty responding under the influence of alcohol. This inter-
pretation is supported by the evidence that in "go/no go" 
tasks using similar stimuli, short-latency responses are ac-
accompanied by larger LRP's (Gratton et al., 1988; Smith et al., 1995). Such "fast guesses" are characterized by an advanced preparation to respond (Coles et al., 1988; Hackley and Miller, 1995).

The tendency to respond more hastily under the influence of alcohol was confirmed by the reaction time data. Whereas alcohol did not affect accuracy in this task, it significantly 

shrank the reaction time after it was adjusted for psychomotor speed. Although most studies report increased RT 
der under alcohol (Franks et al., 1976), an inverse relationship between RT's and BAC was reported by Landauer and 
Howit (1953), suggesting impulsive responding under the influence of alcohol.

A possibility that an LRP on "no go" trials at the alcohol condition was due to increased task difficulty (Oman et al., 1992) rather than "impulsivity" is not supported by the avail-
able evidence: the overall percentage of response errors was very low (<2%) and was unaffected by the beverage; sub-
jects did not rate the task as being more difficult under alco-
hol; the LRP in juice conditions was absent and not relatively 
smaller compared to alcohol.

Similar to the LRP results, the frequency-domain analysis 
indicated that alcohol inebriation resulted in a decrease in LERSP (indicating larger desynchronization) of the mu-
refard for the "no go" words, only. Previous studies have shown that larger mu-theta desynchronizations precede 

task movements resulting from stronger muscle contrac-
tions (Saakec and Pfurtscheller, 1996). Thus, the current 
LERSP results can also be interpreted as indicating that the motor response system may be prematurely engaged under low doses of alcohol.

Increased impulsivity under the influence of alcohol has 
been likened to disinhibition. It has been suggested that lon-
term alcohol use results in disinhibition and motor behavior. Par-
sons et al. (1972) reported that chronic alcoholics were 
unable to suppress fast responding in a task that required slow 

tmotor control. A rather low alcohol dose (peak BAC of 
0.04%) administered to social drinkers significantly reduced 
the latency to the onset of petile tongue while listening to 
an erotic tape (Wilson and Nusser, 1964). These effects may result from the general psychomotor stimulant proper-
ties of alcohol (Wise, 1988) and may be related to an impair-
ment in frontal control of behavior (Peterson et al., 1950).

The possible use of the LRP as a physiological index of 

alcohol-induced impulsiveness is further supported by the 

correlational data obtained in this study. Due to the small 

sample size, these data should be considered preliminary and
will need to be replicated. Nevertheless, correlation trends were obtained between the alcohol-induced LRP on "no go" trials and personality traits such as childhood hyperactivity, psychoticism (Eysenck's P) and socialization, with the common variance of 60% or more. Impulsivity/disinhibition as a reversal of suppression of behavior is a construct that is very difficult to operationalize and measure directly. Yet, it seems to have been measured indirectly as an underlying factor in the aforementioned traits measured in this experiment. Those participants who, when intoxicated, inappropriately exhibited the largest LRP on "no go" trials, also had higher scores on the traits related to hyperactivity/impulsivity and anti-social tendencies. These traits form a cluster termed "antisocial personality disorder" (Shir and Trull, 1994) that correlate highly with chronic alcohol use (Goebel, et al., 1989). Nagoshi et al. (1991) reported a significant correlation between impulsivity and self-reported alcohol use, as well as drinking problems, in a large sample. Underlying commonalities between impulsivity and alcohol abuse are also substantiated by their shared neurological markets (Virkkunen and Linnoila, 1993; Zuckermand, 1993). This may be suggestive of a preexisting neurological milieu in certain individuals that is associated with a set of over-behaviors commonly described as impulsive, hyperactive and even aggressive and which, in turn, is susceptible to alcohol (Pihl, et al., 1993).

In conclusion, the current study demonstrates a premature and inappropriate activation of the motor-response system under low levels of alcohol using two physiological measures, the lateralized readiness potential and the mu-rhythm. The former measure correlates with personality factors that have been associated with impulsiveness, suggesting that it may be used as an on-line physiological index of preparedness to act impulsively and as a tool to investigate abnormal information processing under alcohol.

References


