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SEPARATE AND COMBINED EFFECTS OF CHRONIC ADMINISTRATION OF ENERGY DRINK AND ALCOHOL ON THE LEARNING BEHAVIOR OF FEMALE ALBINO WISTAR RATS

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ABSTRACT

Rising energy drink–alcohol co-consumption raises cognitive concerns, yet evidence on their combined effects on female learning behaviour remains limited. This study therefore examined the separate and combined effects of energy drink and alcohol on learning behavior in female albino Wistar rats. Twenty-eight female rats were randomly assigned to four groups (n = 7): control (distilled water), energy drink, alcohol, and combined energy drink plus alcohol. Energy drink (Red Bull®; 1.0 ml/kg) and alcohol (0.25 ml/kg) were administered orally for 28 consecutive days. Learning performance was assessed using a T-maze task, with latency to locate a food reward recorded 30 minutes after daily administration. Data were analyzed using one-way analysis of variance (ANOVA). The results revealed a significant main effect of treatment on learning performance, $F(3, 24) = 6.01$, $p = .003$. Rats that received the energy drink alone exhibited significantly shorter latencies compared with the control group, indicating enhanced learning efficiency. Alcohol administration alone did not significantly affect learning performance. In contrast, rats exposed to the combined energy drink and alcohol treatment displayed the longest learning latencies, suggesting impaired cognitive performance relative to the energy drink-only condition. These findings indicate that while energy drink consumption may transiently facilitate learning, its co-consumption with alcohol may negate these benefits and impair cognitive function. The study underscores the potential neurobehavioral risks associated with alcohol–energy drink combinations.

Introduction

Learning is a fundamental neurocognitive process involving experience-dependent changes in behavior mediated by synaptic plasticity within distributed neural networks, particularly the hippocampus and prefrontal cortex (Kandel et al., 2021; Ormrod, 2020). Learning efficiency depends on intact neurotransmitter systems and balanced excitatory–inhibitory signaling, both of which are highly sensitive to psychoactive substances (Squire et al., 2022).

Alcohol (ethanol) is a central nervous system depressant that disrupts learning and memory through potentiation of γ-aminobutyric acid (GABAergic) inhibition and suppression of glutamatergic neurotransmission, particularly N-methyl-D-aspartate (NMDA) receptor activity (Abrahao et al., 2017). Chronic or repeated alcohol exposure impairs long-term potentiation (LTP), reduces hippocampal neurogenesis, and compromises memory consolidation (White & Swartzwelder, 2019).

In contrast, energy drinks are stimulant beverages containing high concentrations of caffeine, taurine, sugars, and other psychoactive compounds. Caffeine acts primarily as an adenosine A_1/A_2A receptor antagonist, increasing dopaminergic and noradrenergic activity and transiently enhancing arousal, attention, and reaction time (Curran & Marczinski, 2017). However, excessive or repeated caffeine exposure is associated with anxiety, sleep disruption, impaired cognitive stability, and reduced learning efficiency, particularly when combined with metabolic stressors such as high sugar intake (Temple et al., 2022).

The co-consumption of alcohol mixed with energy drinks (AmED) has emerged as a significant global public health concern, especially among young adults and university populations (Marczinski & Fillmore, 2014; Verster et al., 2018). The stimulant properties of energy drinks can mask subjective alcohol intoxication without reversing cognitive or motor impairment, creating a dissociation between perceived and actual performance—a phenomenon commonly described as “wide-awake drunkenness” (O’Brien et al., 2008).

Preclinical studies demonstrate that AmED produces neurobehavioral effects distinct from either substance alone. Rodent models show that AmED enhances behavioral sensitization to ethanol, increases motivation for alcohol self-administration, and disrupts hippocampal synaptic plasticity more severely than alcohol exposure alone (Ferreira et al., 2013; Petribu et al., 2023). Importantly, adolescent and adult exposure to AmED has been associated with long-lasting alterations in learning-related brain regions, including reduced synaptic efficiency and altered dopamine signaling (Williams et al., 2022).

Despite growing evidence of sex differences in substance sensitivity (Balogun, S.K., et al , 2020a; Balogun, et al, 2020b), most experimental studies on alcohol and energy drinks disproportionately focus on male subjects. Female rodents exhibit distinct hormonal modulation of learning, stress responsivity, and dopaminergic function, which

may alter vulnerability to psychoactive substances (Becker & Koob, 2016). Estrogen, in particular, interacts with hippocampal plasticity and memory consolidation, potentially modifying alcohol- and caffeine-induced cognitive effects (Barha & Galea, 2013).

Given these biological differences, findings derived from male-only models may not generalise to females. The present study therefore focuses exclusively on female albino Wistar rats, addressing a critical gap in the literature and aligning with current recommendations for sex-inclusive neuroscience research (NIH, 2022).

Rodent models remain indispensable for controlled investigation of substance-induced neurobehavioral changes. Rats share substantial genetic, neurochemical, and anatomical similarities with humans and allow precise manipulation of dosage, exposure timing, and behavioral assessment that is not feasible in human studies (Leung & Jia, 2016). Female Wistar rats are particularly suitable for learning paradigms due to their well-characterised cognitive profiles and sensitivity to pharmacological manipulation.

Although alcohol and energy drinks independently affect learning and memory, empirical evidence directly comparing their separate versus combined effects on learning behavior remains limited. Existing studies frequently examine AmED as a single exposure condition, making it difficult to determine whether observed cognitive deficits reflect additive effects or synergistic neurotoxicity. Furthermore, most available animal studies focus on adolescent or male subjects, leaving the effects on adult females insufficiently explored. This gap is particularly concerning given sex-specific neuroendocrine modulation of learning and substance sensitivity. Consequently, there is inadequate experimental evidence clarifying how alcohol alone, energy drinks alone, and their combination differentially influence learning behavior in adult female subjects.

This research attempts to answer the following research question;

1. what effect does energy drink administration have on learning behavior in female albino Wistar rats?

2. what effect does alcohol administration have on learning behavior in female albino Wistar rats?

3. does combined administration of alcohol and energy drinks produce a differential effect on learning behavior compared to separate administration?

The following hypotheses were tested to answer the research questions

1. Energy drink administration will significantly affect learning behavior in female albino Wistar rats.

2. Alcohol administration will significantly affect learning behavior in female albino Wistar rats.

3. Combined administration of alcohol and energy drinks will produce a significantly different effect on learning behavior than either substance alone.

METHODOLOGY

Research Design

The study adopted a randomized controlled experimental design with a between-subjects factorial structure. Two independent variables were investigated: energy drink (Red Bull®) administration and alcohol administration, each with two levels (present vs. absent). The dependent variable was learning performance, operationalized as latency to locate food reward in a T-maze task.

Animals were randomly assigned to one of four experimental conditions: control (distilled water), energy drink only, alcohol only, and combined energy drink plus alcohol.

Study Setting

The experiment was conducted in the animal laboratory of the Department of Psychology, University of Ibadan, Nigeria, under standard laboratory conditions suitable for behavioral neuroscience research.

Experimental Animals

Twenty-eight (28) female albino Wistar rats were used for the study. The rats were young adults and were housed in standard laboratory cages under controlled environmental conditions (12-hour light/dark cycle, ambient temperature, and adequate ventilation). Animals were allowed free access to standard rat chow and water throughout the study.

Following a 14-day acclimatization period, the rats were randomly allocated into four groups (n = 7 per group):

(i) Control group (distilled water)

(ii) Energy drink group

(iii) Alcohol group

(iv) Energy drink + alcohol group

Animal identification was achieved using non-invasive tail markings. All procedures involving animals were carried out in accordance with internationally accepted guidelines for the care and use of laboratory animals.

Drugs and Dosage

The energy drink used was Red Bull®, while alcohol was administered as an undiluted ethanol solution. Dosages were calculated based on individual body weight and administered orally using an oral cannula.

(i) Energy drink: 1.0 ml/kg body weight

(ii) Alcohol: 0.25 ml/kg body weight

(iii) Combined group: received both substances at the same respective dosages

(iv) The control group received an equivalent volume of distilled water.

Procedure

Following acclimatization, animals received daily oral administration of their assigned treatment for 28 consecutive days. Body weights were recorded regularly to ensure accurate dosage administration.

Thirty (30) minutes after each daily treatment, learning performance was assessed using a T-maze apparatus. Food reward was placed consistently in one arm of the maze. Each rat was placed at the start arm, and the latency to locate the food reward was recorded in seconds using a stopwatch.

Learning performance was assessed across three trials per testing session, and mean latency scores were computed. Reduced latency across trials and days was interpreted as improved learning performance.

All behavioral testing was conducted under similar environmental conditions to minimize extraneous variability.

Statistical Analysis

Data were analyzed using one-way analysis of variance (ANOVA) to examine differences in learning performance across the four experimental groups. Statistical significance was evaluated at $p < .05$. Where appropriate, post hoc comparisons were conducted to identify specific group differences.

RESULTS

Table 1 presents the descriptive statistics for learning performance, measured as latency (in seconds) to locate the food reward in the T-maze across the four experimental groups.

Table 1: Descriptive statistics showing the mean time of performance on learning behavior

Descriptives						
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
ENERGY DRINK	7	57.5200	38.85966	14.68757	21.5808	93.4592
ALCOHOL	7	93.2571	62.08938	23.46758	35.8340	150.6802
COMBINED	7	159.0229	46.72665	17.66101	115.8079	202.2378
CONTROL	7	127.1814	36.76660	13.89647	93.1780	161.1849
Total	28	109.2454	58.85212	11.12200	86.4249	132.0658

From Table 1, rats administered energy drink only demonstrated the shortest mean latency ($M = 57.52$, $SD = 38.86$), indicating superior learning performance relative to the other groups. In contrast, rats exposed to the combined energy drink and alcohol treatment exhibited the longest mean latency ($M = 159.02$, $SD = 46.73$), suggesting poorer learning performance. The alcohol-only group ($M = 93.26$, $SD = 62.09$) and the control group ($M = 127.18$, $SD = 36.77$) showed intermediate performance levels. Overall, substantial variability in learning performance was observed across treatment conditions, as reflected in the standard deviations and confidence intervals.

A one-way analysis of variance (ANOVA) was conducted to examine the effect of treatment condition (energy drink, alcohol, combined energy drink and alcohol, and control) on learning performance. The result is shown in Table 2.

Table 2: One-Way ANOVA showing learning performance across the four treatment conditions (Energy Drink, Alcohol, Combined, and Control).

ANOVA					
TIME					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	40114.464	3	13371.488	6.009	<.05
Within Groups	53401.966	24	2225.082		
Total	93516.430	27			

The ANOVA result shows a significant main effect of treatment on learning performance, $F(3, 24) = 6.01$, $p = .003$ ($p<.05$). This implies that the mean learning times differed significantly among the four groups.

To identify the specific group differences underlying the significant omnibus effect, Tukey's Honestly Significant Difference (HSD) post hoc test was performed. The result is shown in Table 3.

Table 3: Turkey HSD Post Hoc Test result showing pairwise comparisons between Treatment groups.

Multiple Comparisons				
Mean Differences				
	ENERGY DRINK	**ALCOHOL**	**COMBINED**	**CONTROL**
ENERGY DRINK				

ALCOHOL	35.73714			
COMBINED	101.50286*	65.76571		
CONTROL	69.66143*	33.92429	-31.84143	

NB: $p < .05$

The result of the post hoc analysis showed that the energy drink group differed significantly from the combined energy drink and alcohol group ($p = .003$) and from the control group ($p = .050$), with the energy drink group demonstrating faster learning performance. However, the difference between the energy drink group and the alcohol-only group was not statistically significant ($p = .501$). No other pairwise comparisons reached statistical significance ($p > .05$), including comparisons between the alcohol-only group and the control group, as well as between the combined treatment group and the control group.

Figure 1 illustrates the mean learning latencies for the four experimental groups with corresponding 95% confidence intervals, visually highlighting the superior performance of the energy drink group and the impaired performance associated with the combined treatment condition.

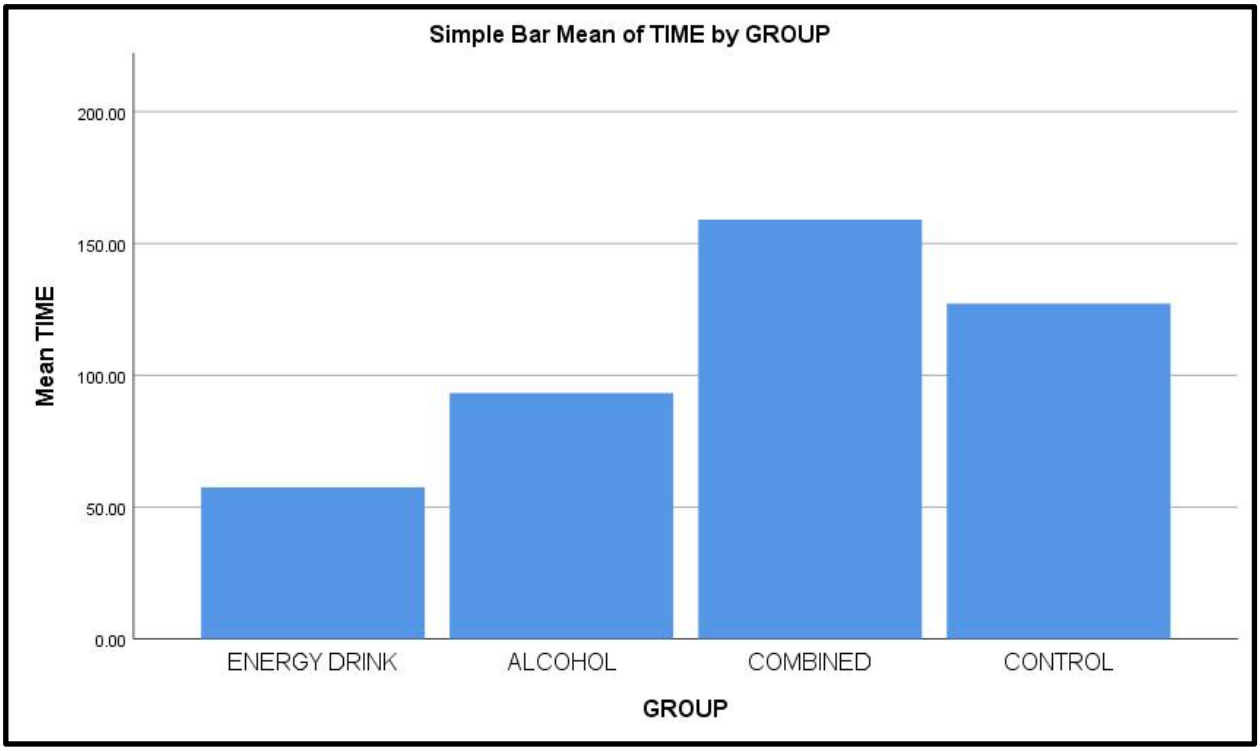

Figure 1: Bar chart showing the mean learning behavior performance scores with 95% confidence intervals for the four experimental groups (Control, Alcohol, Energy Drink, and Combined).

DISCUSSION

The present study examined the separate and combined effects of an energy drink (Red Bull®) and alcohol on learning performance in female albino Wistar rats. Learning was assessed using T-maze latency, a well-established measure of spatial learning and cognitive efficiency. Overall, the findings demonstrate differential effects of energy drink, alcohol, and their combination on learning behavior, partially supporting the study hypotheses.

The first hypothesis, which predicted a significant effect of energy drink administration on learning behavior, was supported. Rats that received the energy drink alone exhibited significantly shorter latencies in the T-maze compared with the control group, indicating enhanced learning performance.

This finding is consistent with extensive evidence that caffeine, the primary psychoactive component of energy drinks, exerts facilitatory effects on cognitive performance, particularly on attention, vigilance, and learning speed. Caffeine acts mainly as a non-selective adenosine A_1 and A_2A receptor antagonist, thereby reducing inhibitory adenosinergic tone and increasing neuronal excitability, especially within cortico-hippocampal circuits critical for learning and memory (Fredholm et al., 2022; Nehlig, 2018). Enhanced dopaminergic and cholinergic transmission following caffeine intake has also been linked to improved task acquisition and faster response times in rodents (Borota et al., 2014; Pan et al., 2023).

The present findings align with prior animal studies reporting improved maze performance and spatial learning following low-to-moderate caffeine exposure (Angelucci et al., 2019; Kaster et al., 2015). Importantly, these facilitatory effects appear dose-dependent, with moderate doses enhancing

cognition while higher doses may impair performance through anxiety-like effects or locomotor hyperactivity (Nehlig, 2018). The improved learning observed in the energy drink group therefore likely reflects acute CNS stimulation rather than long-term cognitive enhancement.

The second hypothesis, which proposed a significant effect of alcohol alone on learning behavior, was not supported. Although rats exposed to alcohol showed numerically shorter latencies than controls, the difference did not reach statistical significance.

Alcohol is widely recognized as a central nervous system depressant that disrupts learning and memory through its effects on GABAergic, glutamatergic, and hippocampal plasticity mechanisms (Crews et al., 2019; Vetreno & Crews, 2021). However, the absence of a significant impairment in the present study may be attributable to several factors. First, the dose administered may have been relatively low, potentially falling below the threshold required to elicit marked cognitive deficits. Second, low doses of alcohol have been reported to produce transient stimulant-like effects, including increased locomotion and reduced anxiety, which may partially offset impairments during simple learning tasks (Pohorecky, 2016).

Comparable findings have been reported in rodent studies showing minimal or inconsistent effects of low-dose alcohol on acquisition speed in maze tasks, particularly when exposure is acute or subchronic (Cippitelli et al., 2017). Thus, the present result suggests that, under the current experimental conditions, alcohol alone did not substantially disrupt learning performance in female Wistar rats.

The third hypothesis, predicting a significant effect of the combined administration of energy drink and alcohol, was not supported when compared directly with the control group. Nevertheless, the combined treatment group displayed the poorest numerical learning performance and differed significantly from the energy drink-only group.

This pattern is highly consistent with the growing literature on alcohol mixed with energy drinks (AmED), which indicates that caffeine does not reverse alcohol-induced cognitive impairment but instead masks subjective sedation while preserving or worsening objective deficits (Marczinski & Fillmore, 2014; Benson et al., 2020). In animal models, combined caffeine–alcohol exposure has been shown to disrupt hippocampal synaptic plasticity, increase behavioral disorganization, and impair learning despite heightened arousal (Petribu et al., 2023; Pan et al., 2023).

The markedly slower learning observed in the combined group supports the concept of “wide-awake intoxication,” whereby stimulant-induced alertness coexists with alcohol-related cognitive dysfunction (Marczinski, 2018). Although the difference from the control group did not reach statistical significance, the magnitude and direction of the effect suggest a biologically meaningful impairment that may have been constrained by sample size. The significant contrast between the combined group and the energy drink group further underscores the antagonistic interaction between caffeine and alcohol on learning processes.

The exclusive use of female rats is an important contribution, given increasing evidence that sex differences influence psychostimulant and alcohol effects on cognition. Female rodents often exhibit heightened sensitivity to caffeine and alcohol due to hormonal modulation of adenosine and dopaminergic systems (Becker & Koob, 2016; Finn, 2020). The pronounced enhancement observed with energy drink administration and the distinct impairment pattern with combined exposure highlight the need for sex-specific analyses in substance-related cognitive research.

Conclusion

This study demonstrates that energy drink consumption alone significantly facilitates learning performance in female albino Wistar rats, likely through caffeine-mediated central nervous system stimulation. Alcohol alone, at the administered dose, did not significantly alter learning behavior. Critically, the combined administration of energy drink and alcohol produced the poorest learning performance, particularly when contrasted with the energy drink-only condition, indicating a detrimental interaction between the stimulant and depressant substances.

Overall, the findings suggest that while energy drinks may transiently enhance learning efficiency, co-consumption with alcohol undermines cognitive performance, reinforcing concerns about the neurobehavioral risks associated with AmED use.

RECOMMENDATIONS

Based on these findings, the following recommendations are proposed:

(i) Public health interventions should intensify awareness campaigns highlighting the cognitive risks associated with mixing alcohol and energy drinks, particularly among young adults and students.

(ii) Regulatory agencies should consider stricter controls on the marketing and availability of alcohol–energy drink combinations.

(iii) Future studies should employ larger sample sizes, include both sexes, and investigate dose–response relationships to clarify threshold effects.

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