# Moderative effect of educational attainment on the correlation between alcohol-specific reward responsiveness and alcohol use disorder (AUD) severity

## Abstract

A greater understanding of the relationships between risk factors for alcohol use disorder (AUD) can aid early intervention and improve prognosis for people with AUD. The present study aims to determine whether alcohol-specific reward responsiveness affects AUD severity in adults and investigate how educational attainment moderates this relationship. Electroencephalogram (EEG) recordings from participants with varying severities of AUD were analysed to quantify the Reward Positivity (RewP) event-related potential (ERP) as a neurophysiological measure of alcohol-specific reward responsiveness. Whilst the results indicate that alcohol-specific reward responsiveness has some effect on AUD severity in adults, and that educational attainment moderates this relationship such that its strength decreases for individuals with greater years of formal schooling, these relationships were not found to be statistically significant. Hence, the present study finds no significant effect of alcohol-specific reward responsiveness on AUD severity in adults, and no significant moderative effect of educational attainment on this relationship.

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## Literature Review

An estimated 400 million people, which is 7% of the global population aged 15 or over, have AUD (World Health Organization, 2024). As of 2023, 10.2% of people in the US aged 12 or over have AUD, according to the 2023 National Survey on Drug Use and Health (Substance Abuse and Mental Health Services Administration, 2023). The National Institute on Alcohol Abuse and Alcoholism (2020) defines alcohol use disorder as a brain disorder characterised by impaired control over one’s alcohol consumption in spite of adverse social, occupational or health consequences. Individuals with this condition display abnormalities in the neural function of reward responsiveness, which is the degree to which an individual experiences positive responses to rewards (Taubitz et al., 2015). Reward responsiveness is defined as a ‘construct’ that falls under the domain of positive valence systems within the Research Domain Criteria framework, which consists of six ‘domains’ of basic neurobehavioural function (National Institute of Mental Health, n.d.).

The Reward Positivity (RewP) is a neurophysiological measure of reward responsiveness. RewP is an event-related potential (ERP) component, which is a voltage change generated in the brain in response to a stimulus. RewP is characterised by a positive deflection that peaks at frontocentral electrode sites roughly 250-300ms after reward feedback (Proudfit, 2015). RewP amplitude, which is the strength of the electrical signal in units of microvolts (μV), is positively correlated with self-reported reward responsiveness (Bress & Hajcak, 2013) and activation of the ventral striatum and medial prefrontal cortex (Carlson et al., 2011; Gehring & Willoughby, 2002) which are structures involved in the reinforcement of rewarding behaviours. RewP amplitude is also correlated with the degree to which an individual “likes” an image, demonstrating that RewP is sensitive to the affective (i.e. emotional) features of reward (Brown et al., 2022).

The literature presents mixed evidence supporting a correlation between AUD and both enhanced and reduced reward responsivity. Some studies have found that reward responsiveness is positively correlated with alcohol intake (Loxton & Dawe, 2001) and early-onset drinking (Pardo et al., 2007), which are known risk factors for AUD.Hazardous drinkers demonstrate attentional bias to sensory-specific features of alcohol such as imagery and smells (Roberts & Fillmore, 2015; Weafer & Fillmore, 2013), suggesting that they also display enhanced alcohol-specific reward responsiveness. Indeed, preliminary evidence indicates a positive correlation between alcohol-specific RewP amplitude and AUD severity (Singh et al., 2023). However,other studies have shown that alcohol consumption leads to neuroadaptations associated with reduced reactivity to non-alcohol-related rewards (Koob, 2013).Alcohol Use Disorder Identification Test (AUDIT) score, which is a measure of AUD severity (Babor et al., 2001), is also associated with reduced reward responsiveness in adolescents specifically (Aloi et al., 2020).

The study by Aloi and others suggests that these mixed findings regarding the correlation between reward responsiveness and AUD severity can be attributed to the moderative effect of demographic factors on the relationship between reward responsiveness and AUD severity. One such potential factor is educational attainment (EA) in terms of years of formal schooling. Education affects an individual’s health literacy and emotional regulation ability. Individuals with lower EA may be more likely to engage in hazardous drinking due to their increased exposure to social stress and low health literacy regarding the hazards of alcohol use (Cerdá et al., 2011). Indeed, higher EA is associated with a decreased likelihood of heavy drinking (Caldwell et al., 2008) and alcohol dependence (Rosoff et al., 2021).

Although no study has examined how the strength and direction of the RewP-AUD severity correlation varies with educational attainment, preliminary evidence indicates that impulsivity, which is related to reward responsiveness, is directly correlated with alcohol dependence severity and that an individual’s years of educational attainment moderates the relationship between impulsivity and alcohol dependence severity such that the correlation weakens with greater educational attainment (Liu et al., 2020). This study used the subjective, self-reported Barrett Impulsivity Scales (BIS) Reward Responsiveness score to index impulsivity. The present study will address this limitation by employing RewP as a neurophysiological measure of reward responsiveness. The available evidence suggests that the importance of alcohol-specific reward responsiveness as a contributing factor to the development of AUD is diminished in individuals with greater educational attainment. Therefore, given the available evidence for correlations between EA, AUD severity and reward responsiveness, the present study hypothesises that an individuals’ extent of educational attainment moderates the effect of alcohol-specific reward responsiveness on AUD severity such that the correlation is positive and weakens with increased educational attainment.

The results of the proposed study may help inform the methodological approach with which researchers account for the moderative effect of demographic variables such as educational attainment when analysing the correlation between reward sensitivity and AUD severity, potentially enabling them to obtain more robust findings. More broadly, a greater understanding of the interactions between risk factors for AUD can aid early intervention and improve prognosis for patients with AUD.

## Scientific Research Question

1. How does alcohol-specific reward responsiveness affect alcohol use disorder (AUD) severity in adults?
2. How does educational attainment moderate the above relationship? (i.e. how does it affect the strength and direction of the correlation?)

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## Hypothesis

1. H0: Alcohol-specific reward responsiveness does not affect AUD severity in adults (β1 = 0; see Methodology).

HA: Alcohol-specific reward responsiveness affects AUD severity in adults such that the correlation is positive (β1 > 0).

1. H0: Educational attainment does not moderate the effect of alcohol-specific reward sensitivity on AUD severity in adults (β3 = 0; see Methodology).

HA: Educational attainment moderates the effect of alcohol-specific reward sensitivity on AUD severity in adults such that the correlation weakens with greater years of educational attainment (β3 < 0).

## Methodology

**Data collection**

The raw dataset (Singh & Cavanagh, 2023) contains EEG data from 28 participants with AUD and 26 healthy controls. Each data point is paired with metadata of the participant’s educational attainment in terms of years of formal schooling and AUDIT score. EEG data was recorded at 0.01-100Hz from 64 electrodes positioned on the scalps of participants whilst they completed a reinforcement learning task designed by Brown et al (2022). They were shown one of four specific visual cues and instructed to learn the “correct response” (pushing a certain button) based on subsequent feedback (reward or punishment). The specific cue determined whether an image of a puppy or alcohol was presented after button selection. After a temporal delay, feedback was given in the form of a green screen indicating reward or a red screen indicating punishment. This temporal separation of the novel image and feedback controls for the N2 ERP component, which is evoked by novel stimuli (Patel & Azzam, 2005) and otherwise obscures the RewP (Brown & Cavanagh, 2020), ensuring that any observed neural signals are a valid measure of reward responsiveness as opposed to novelty. Each participant completed 80 trials of each condition (puppy and alcohol imagery) enabling sufficient reliability of the averaged individual RewP amplitude.

**Data processing and cleansing**

The data cleansing pipeline implemented the same parameters as the study which produced the dataset (Singh et al., 2023). All raw data was processed with MNE Python (Gramfort et al., 2013). It was filtered from 0.01-100Hz to 0.01-20Hz to reduce noise as human EEG signals are generally in the latter range. The average reference was computed, then the data was re-referenced to the TP9 and TP10 electrodes placed on the mastoid bones (i.e. the electrical potential difference at each electrode is determined in relation to these electrodes) to minimise noise. Independent Component Analysis (ICA) (Makeig et al., 1996) is a computational method for discerning a signal from independent sources which can obscure it, such as brain and eye electrical activity. Reducing noise is essential for ensuring that the results represent a valid measure of brain activity as opposed to other sources of electromagnetic activity. The EEG data was epoched from -2000 to 6000ms around feedback onset, and each epoch was baseline corrected to -200 – 0ms before feedback onset. The RewP signal was quantified as the average amplitude of the electrical signal from 200-400ms after feedback onset at the Cz electrode. The RewP amplitude in response to puppy imagery was averaged across 80 trials, then subtracted from the averaged amplitude of RewP in response to alcohol imagery, to compute the alcohol-puppy RewP amplitude difference, which isolates alcohol-specific reward sensitivity.

**Moderated regression analysis**

Lastly, regression analysis was conducted in R to analyse the effect of AUDIT score on RewP amplitude and the moderative effect of EA on this relationship. The mean-centered alcohol-puppy RewP amplitude difference (RewP score) and mean-centered educational attainment (EA) were computed by subtracting the mean value from each individual value. Then, the interaction term, which is the product of the independent and moderator variables, was calculated by multiplying the mean centered-RewP score and years of EA together. Mean-centered values were used to minimise multicollinearity between the predictor variables (RewP score, EA) and interaction term (RewP score × EA). The form of the regression equation was:

y = α + β1x + β2z + β3x\*z

where y = AUDIT score, x = mean-centered RewP score, z = mean-centered EA and x\*z = interaction. As per the null hypothesis, R conducted one-sample t-tests comparing each coefficient with the values of β1 = 0 and β3 = 0. The p-value of the β1 coefficient indicated whether the effect of RewP score on AUDIT score was significant, and hence used to assess null hypothesis 1. The p-value of the β3 coefficient indicated whether the moderation effect was significant, and hence used to assess null hypothesis 2.

All code used for this analysis are available at: <https://github.com/elzhang19/EA-AUD-reward>

## 

## Results

|  |  |
| --- | --- |
|  | **Hazardous drinkers** |
| **Number of participants (# female)** | 28 (16) |
| **Age** | 38.60 (9.43) |
| **Years of Education** | 15.00 (2.30) |
| **AUDIT** | 10.50 (5.57) |

Table 1: Demographics of participants. Numbers are formatted as mean (standard deviation), except for sample size count.

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Figure 1**: Output of moderated regression model, computed in R**. ‘rewpc’ represents the mean-centered alcohol-puppy RewP amplitude difference (μV). ‘EA\_years’ represents the educational attainment of the individual (years). ‘rewpc:EA\_years’ represents the interaction term (rewpc × EA\_years).

|  |  |
| --- | --- |
|  | **A graph with a line and dots  Description automatically generated** |
| Figure 2: **Scatterplot of the relationship between alcohol-specific reward responsiveness and AUD severity**. Gradient β1 = 0.9052 (p=0.1455). | Figure 3: **Scatterplot of the relationship between educational attainment and AUD severity**. Gradient β2 =1.0300 (p=0.0725). |

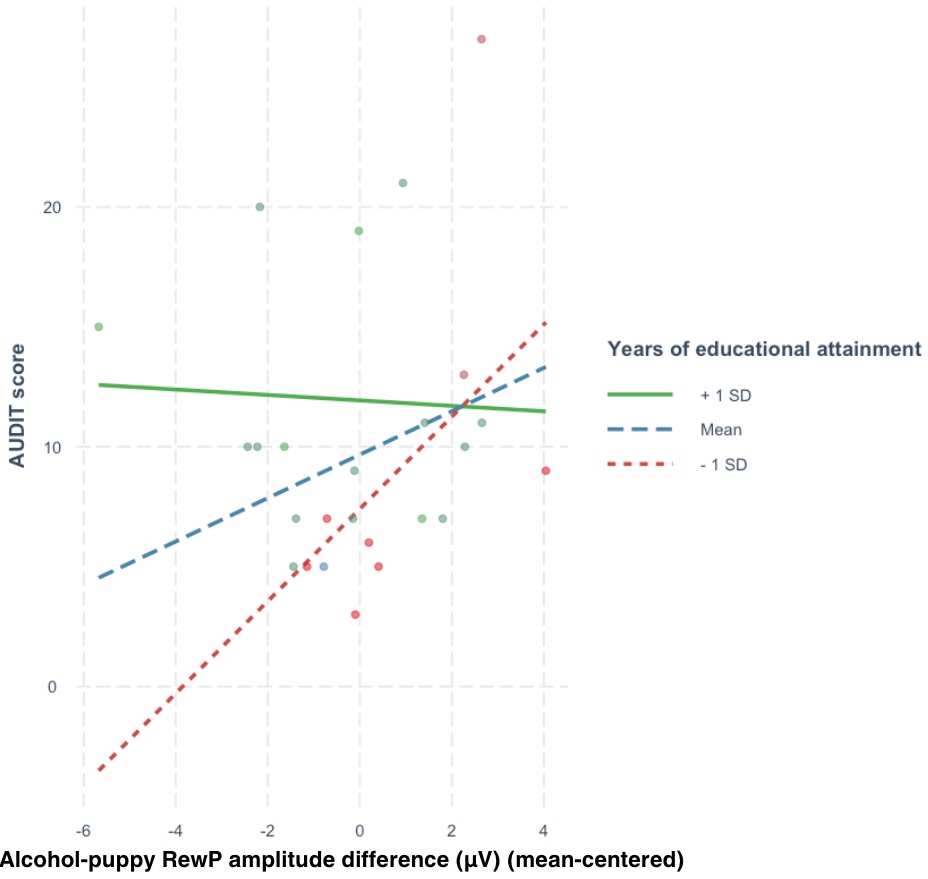
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Figure 4: **Moderative effect of educational attainment on the relationship between alcohol-specific reward responsiveness and AUD severity.** The green points represent individuals with EA more than one standard deviation above the mean; the blue represents individuals with EA within one standard deviation of the mean; the red represents individuals with EA more than one standard deviation below the mean. Gradient of interaction term β3 = -0.4838 (p=0.0843).

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## Discussion

***Demographics of study participants***

To ensure the distribution of AUDIT scores was not skewed, results from control participants, who had an AUDIT score of 1-3, were excluded. Only results from hazardous drinkers (n=28) were used. Inclusion criteria for the hazardous drinkers group included: age 22-55 years; self-identify as a “moderate to hazardous/binge/weekly drinker”; AUDIT score of greater than 8 for males, and greater than 7 for females. Refer to the original study for further demographic details and exclusion criteria (Singh et al., 2023). As seen in Table 1, participants consisted of 16 females and 12 males, meaning the study has a slightly greater proportion of females than the 50.9% female and 49.1% male composition of the 2020 US adult population (United States Census Bureau, 2020). As seen in Table 1, hazardous drinkers attained a mean of 15.00 years of education, which is slightly greater than the mean years of education of 13.58 years for US adults aged 25 or over according to the 2023-24 UN Human Development Report (United Nations, 2024). Due to the small sample size, and the difference between the mean educational attainment and gender composition of this sample with that of the US adult population, the sample is not precisely representative of the overall population.

***Analysis of results***

Figure 2 shows that alcohol-specific reward responsiveness and AUD severity are positively correlated, as indicated by the gradient of the line of best fit, β1 = 0.9052. This supports existing findings regarding the positive correlation between traits related to reward responsiveness and AUD severity (Liu et al., 2020). However, assuming a significance level of α=0.05, this correlation is not statistically significant (p=0.1455>0.05). Hence, the results refute the first hypothesis that the correlation between alcohol-specific reward responsiveness (as indexed by RewP) and AUD severity is positive. This lack of a significant result is not unexpected, given the conflicting evidence for the direction and significance of the effect of alcohol-specific reward responsiveness on AUD severity.

The scatterplot in Figure 4 indicates that the correlation between alcohol-specific reward responsiveness and AUD severity, which is positive amongst individuals with low educational attainment (fewer than one standard deviation below the mean), weakens amongst individuals with high educational attainment (greater than one standard deviation above the mean) as indicated by the sparse distribution of points around the line of best fit for high EA compared to that around the line of best fit for low EA. The negative gradient of the interaction term (β3 = -0.4838) supports this interpretation that the effect of reward responsiveness on AUD severity decreases as educational attainment increases. This aligns with previous existing findings about traits related to reward responsiveness such as impulsivity (Liu et al., 2020). However, this moderation effect is not statistically significant (p=0.0843>0.05), refuting the second hypothesis that the correlation between RewP and AUD severity is positive but weakens with increasing educational attainment.

Interestingly, the correlation between EA and AUD severity (β2 = 1.0300, p=0.0725; see Figure 3) is more statistically significant than that between the interaction term and AUD severity, indicating that educational attainment itself is a better predictor of AUD severity than the combined effect of educational attainment and reward responsiveness. Indeed, existing findings indicate a robust inverse relationship between educational attainment and alcohol dependence, which aligns with the current knowledge that less educated individuals generally possess poorer health literacy and awareness of the health risks of alcohol, and socioeconomic instability which is conducive to stress (Cerdá et al., 2011).

***Limitations and future directions for research***

The lack of significant results may be attributed to the small sample size of the study (n=28). As mentioned previously, the mean age and educational attainment of the sample slightly differ from that of the US adult population, indicating that the sample was not exactly representative of the overall population. This is unsurprising, given the small sample size. Hence, further studies should employ larger sample sizes that are more representative of the overall population.

Furthermore, the available demographic and clinical metadata describing each participant lacks key details. The exact types of formal education undertaken by each participant is unknown, as well as other factors of socioeconomic status (SES) such as income, occupation and financial security that are related to educational attainment and may contribute to AUD severity. Further research into moderated regression models involving these other socioeconomic factors as moderating variables may contribute to a more complete understanding of their effect on AUD severity and more robust findings.

Whilst neurophysiological measures of psychological functions such as reward responsiveness may be more objective and measurable than behavioural metrics, such as BIS/BAS (Behavioural Activation and Behavioural Inhibition Scores) Reward Responsiveness (Taubitz et al., 2015), a combination of both neurophysiological and behavioural measures of alcohol-specific reward responsiveness may contribute to a more accurate, complete profile of reward sensitivity. This may allow for more robust findings to be obtained.

## Conclusion

The aim of the present study was to determine whether alcohol-specific reward responsiveness affects alcohol use disorder (AUD) severity in adults, and to investigate how educational attainment moderates this relationship. Although existing studies have approached similar research questions by employing behavioural proxies for reward responsiveness such as the BIS-BAS Reward Responsiveness score, the present study analysed EEG recordings to quantify the RewP ERP signal as a neurophysiological measure of alcohol-specific reward responsiveness.

Whilst the data indicates that alcohol-specific reward responsiveness has some effect on AUD severity in adults, and that educational attainment moderates this relationship such that its strength decreases for individuals with greater years of formal schooling, these relationships were not statistically significant. Hence, the data failed to reject both null hypotheses; that there is no significant effect of alcohol-specific reward responsiveness on AUD severity in adults, and that educational attainment is not a significant moderator of this relationship.

The lack of significant findings may be attributed to the lack of demographic and clinical metadata available about the individuals’ educational attainment, such as the types of formal schooling obtained. Additionally, the solely neurophysiological approach to individuals’ reward responsiveness adopted by the present study may have contributed to these insignificant findings. This suggests that researchers should seek to obtain more accurate, holistic profiles of individuals’ reward responsiveness by analysing a combination of neurophysiological and behavioural measures of reward responsiveness. A greater understanding of the interactions between risk factors for AUD can aid early intervention and improve prognosis for patients with AUD.

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