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Principal component regression of academic performance, substance use and sleep quality in relation to risk of anxiety and depression in young adults

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ABSTRACT

Adverse lifestyle factors increase risk of anxiety and depression in young adults. Consequently, neurochemical and neuroanatomical alterations ensue, and may initiate a vicious cycle of mental distress, poor lifestyle choices and academic performance. A total of 558 students from different US colleges completed an anonymous survey on academic performance, daytime sleepiness, substance use and mental distress. Low mental distress in college students positively associated with good academic efforts and limited daytime sleepiness. Mild mental distress correlated with borderline work neglect and with a marginal negative association with Grade-point average (GPA). Severe mental distress correlated with excessive daytime sleepiness and poor academic performance. A System Dynamic model was developed to reflect the integration of these variables with mental distress and academic performance. Our results demonstrate that manageable lifestyle factors contribute to mental health in college students, which become potentially cyclic events that may impact academic performance.

1. Introduction

Mental distress, commonly known as anxiety and depression, in college students is becoming a ubiquitous disorder that carries the risk of future recurrence and substance abuse. A 2010 American College Health Association survey [1] reported that 45.6 percent of students exhibited symptoms of mental distress. Additionally, roughly 75 percent of American adults experience their first episode of mental distress in young adulthood [2]. According to a 2010 National Survey of Counseling Center Directors [3], about 46 percent stated an increase in student population with alcohol abuse problems. Young adults are prone to mental distress due to the incomplete maturation of the prefrontal cortex (PFC), the executive and cogent part of the brain [4]. Neurochemically, an imbalance between the main modulators of neuronal activities, the excitatory glutamate and the inhibitory gamma-aminobutyric acid (GABA), exists in young adulthood. While glutamatergic neurotransmission solidifies during prenatal and immediate postnatal life, (GABA)ergic neurotransmission, particularly in PFC, follows a latent pattern [5]. Therefore, this disparity in the key modulators of neuronal transmission is in part responsible for the neurobehavioral and emotional attitudes of adolescents and young adults.

Brain maturation involves myelination of axons and reinforcement of neurocircuits that project to the emotional centers of the limbic system (LS). Consequently, the cortical-limbic circuit (CLC) that connects PFC with LS is critical for mood regulation and mental wellbeing [6]. Therefore, a matured PFC supports an effective CLC communication and promotes regulation of impulses as well as emotion processing. Psychosocial stress dysregulates CLC's neurotransmission and disturbs the functional connectivity of the amygdala in areas that integrate affective processing [6]. Therefore, the neurochemical discrepancy along with CLC disturbance predispose young adults to anxiety and depression [7]. Additionally, mental distress induces cellular and molecular changes in the brain that lead to neuroendocrine, neurotransmitter, and neuroanatomical disruptions [8–12]. Consequently, variations in neurotransmission may influence the degree of PFC maturation and its cognitive abilities [4,6].

Psychological stress impacts the hippocampus (HC) at different levels, which increases risk of mental distress and poor cognitive functions. This iconic region of the limbic system plays a significant role in motivation, learning and memory. HC is a plastic structure with a neurogenesis potential that is highly vulnerable to metabolic insults. Nevertheless, the neurogenesis capability of HC has been controversial in recent literature [13–16]. HC houses high levels of glucocorticoid and glutamate receptors that regulate the hypothalamic-pituitary-adrenal (HPA) axis activity. Activation of the hippocampal-glucocorticoid receptors reinforce contextual fear memory, which is typically

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mediated by HC and the amygdala through genomic mechanisms [6]. Nonetheless, chronic HPA axis activation associates with loss of dendrites and spines in hippocampal neurons, presumably due to oxidative stress and reduction in neurotrophic factor release [6,17–19]. Therefore, HPA dysregulation and subsequent HC structural modifications induce changes in neurochemistry and neuroplasticity. In addition, these biochemical alterations stimulate neuroinflammation that further disturbs several metabolic and molecular pathways [12,20]. Consequently, neurocircuits responsible for motivation and emotion-processing become dysregulated leading to anxiety and depressive symptoms [21]. Mechanistically, the pro-inflammatory cytokines upregulate the expression of presynaptic reuptake pumps, stimulate the enzymatic degradation of monoamine precursors and increase glutamate excitotoxicity [21,22]. Consequently, alteration in dopaminergic neurotransmission of the reward system induces anhedonia and promotes anxiety, arousal, and fear [23]. These disturbances ultimately affect learning and memory. Therefore, young adults with high stress levels and poor coping mechanisms may be experiencing structural changes that predispose them to mental distress and poor academic performance.

In addition, HC is highly susceptible to damage from negative stimuli such as a low-quality diet, stress, and substance abuse [24–28]. Therefore, exposure to these negative stimuli during a critical window of brain development in adolescence and young adulthood may set the stage for future ailments [29]. In fact, consumption of the Western diet (a prototype of an unhealthy diet) has been associated with an inflated stress reaction in young laboratory animals along with hippocampal volumetric abnormalities [26]. Interestingly, even moderate levels of drinking (14–21 units/week) associated with hippocampal atrophy in middle-aged men and women [30]. In addition, substances of abuse have been associated with cognitive decline presumably due to the rewiring of neurocircuitry that set the stage for further drug seeking [28,31]. Young adults are also known to consume caffeinated beverages as stimulants. Typically, these drinks are addictive due to their caffeine content, which disrupts the circadian rhythm depending on the time of consumption. In fact, sleep, academic performance and mental health interconnect with reciprocal effects [32–34]. A poor sleep pattern halts hippocampal neurogenesis, long-term memory consolidation, and neurotransmitter biosynthesis, which collectively may affect learning and mood [35].

Several reports in the literature describe distinctly the relationship between substance abuse, sleep, academic performance and mental health in young adults [36–38]. However, no study investigated this relationship holistically to expound the inter-connection of different variables and their causal factors on mental distress. Previous work from our laboratory demonstrated that mental wellbeing in young adults promotes motivation to improve diet and healthy habits, which becomes a virtuous cycle [24]. Alternatively, mental distress in the same cohort leads to a loss of motivation to sustain this healthy trend. Based on this line of reasoning, we wished to extend this scope by assessing the integrated influences of various lifestyle factors (sleep, academic attitude, Grade-Point Average (GPA) and substance abuse) on mental distress in young adults. The rationale is that levels of motivation and self-worth differentially affect mental health, which may further influence behaviors. A second aim was to evaluate the effect of substance use, daytime sleepiness, academic attitudes, mental distress on GPA, which could be reflective of cognitive functions. A third aim was to model these relationships using System Dynamic (SD) modeling to explicate the amalgamation of these variables in relation to mental distress and academic performance in college students. Therefore, these aims fill many gaps in the literature. Consequently, our study is the first to broaden the lens on the links between distinct levels of psychological distress and selected behaviors across a sample of students from several U.S. colleges.

2. Methods

2.1. Participants and data collection

The study protocol was approved by the Institutional Review Board at Binghamton University. Participants consented to the study by agreeing to access the survey. Inclusion criteria consisted of adults aged 18 or older and being enrolled in a U.S. college. Data was collected between October 2016 and January 2018. No compensation was provided for completing the questionnaire. An anonymous internet-based survey built in Google forms was distributed via several social media platforms and academic listservs targeting diverse public and private institutions. The survey is comprised of fifty-two questions compiled from four validated questionnaires on alcohol use (Short Michigan Alcohol Screening), daytime sleepiness as a subjective measure of tiredness (Epworth Sleepiness Scale), psychological distress (Kessler-6 Psychological Distress) and academic performance (Academic Performance Rating Scale). Most questionnaires answers were based on a 5-item Likert scale. Demographic questions included gender, age range, race, cumulative GPA, past-semester GPA, class, major, Greek-Life affiliation, current college attended, and highest education sought. Other questions included frequency of non-prescription ADHD drug use, types of ADHD drug used, frequency of alcohol drinking and energy and soft drink consumption.

2.3. Analysis

The newly compiled questionnaire was assessed for the underlying structure using Principal Component Analysis (PCA). The resulting subscales were further tested for internal consistency using the Cronbach's index. To assess suitability of data for PCA and sampling adequacy, Kaiser-Meyer-Olkin Measure and Barlett's test of Sphericity, respectively, were computed [39,40]. PCA uses a correlational matrix that identifies common patterns in a dataset. It simplifies a multi-dimensional system into a two-dimensional scheme while retaining the characteristics that contribute most to the variance. The newly generated set of variables (also known as principal components (PCs)) are independent of one another following an orthogonal rotation. Therefore, PCA is a powerful multivariate data analysis method that could be used for data mining and for identification of patterns within variables. Missing data was handled using the Multivariate Imputation by Chained Equations (MICE) approach in R, which is considered a major method of addressing missing data in research in the statistical literature [41]. Variance estimation after amputation was performed by using jackknife variance estimator in "PLS" package in R. Multicollinearity was assessed using the variance-inflation factors function based on the "CAR" package in R [42]. A robust multivariate analysis (PCR) was employed to identify the latent variables associated with the categorized dependent variables of interest. PCR combines Principal Component Analysis (PCA) with a linear regression (LR) to retain the significant variables in the identified patterns. LR assumes that the independent variables are not significantly correlated. However, in a multiple linear regression model highly intercorrelated predictors may lead to an overfit model with inflated regression coefficients, P values, and R-squared. PCR method takes care of the multicollinearity by using the PCs as new predictor variables to explain the observed variability without considering the response variable. Additionally, PCR adds a degree of bias to the regression estimates and reduces the standard errors [43], which improves accuracy of the results.

2.4. Data partitioning

Observations on mental distress were segregated into three groups: ‘Low mental distress’ for scores between 0–7, scores between 8–12 referred to ‘mild mental distress.’ Scores between13-24 reflected ‘severe mental distress’. This categorization was based on suggestions by

Krynen et al. [44]. Similarly, the dependent variable GPA was further partitioned into the conventional categories; 2.99 and below was characterized as low (less than a B) GPA and 3.0 and above was classified as high GPA (B or above). The rationale behind the dichotomization of the GPA and the cutoff was based on the minimum GPA requirement set by most graduate schools [45].

2.5. Model optimization and validation

To determine the optimal number of PCs to be included in the model, predictive powers of models were compared; the model with the best prediction was retained. Root mean squared error (RMSE) of prediction (RMSEP) was determined for all models. Components selection was based on the lowest RMSE. An RMSEP curve (as a function of the number of components) was used to determine the minimum number of PCs. To select a parsimonious model, the deflection point within the RMSEP curve was used. Dependent and independent variable scores were standardized to better interpret the results. Subsequently, all calculations were based on the standardized variables. Data was analyzed in R (Version 1.1.453 –2009–2018 RStudio, Inc.) and SPSS version 24.0.

3. Results

3.1. Demographics

A total of 558 participants completed the survey, of which 396 are females and 162 are males. Ninety three percent of respondents were between the ages of 18–22, and 7 percent were 23 years or older. One hundred eighty respondents were sophomore, 129 were juniors, 147 were seniors, 63 were freshman and 49 were graduate students. Using ANOVA and Chi square analyses, GPA ($P < 0.001$), never or once a month use of NADHD and no alcohol drinking were statistically significant ($P < 0.05$) (Table 1).

3.2. Construct analysis

Kaiser-Meyer-Olkin Measure was 0.752. Typically, values above 0.6 are considered appropriate. Barlett's test of Sphericity was significant ($X^2 = 5461.7$; df = 903; $P < 0.001$). Cronbach's alpha, which is a measure of internal consistency, was 0.78. Values above 0.70 are typically considered significant.

3.3. Principal component regression

3.3a. Low mental distress as a dependent variable

There was a strong inverse correlation between daytime sleepiness (i.e. likelihood of falling asleep while performing daily activities) and low mental distress ($P = 0.000$). A strong correlation was also detected between studious behaviors and attitudes (such as being interested in learning, strong past semester and cumulative GPA and the belief that academic performance depends on efforts made) and low mental distress ($P < 0.001$). Additionally, there was an inverse correlation between poor academic performance (such as wanting to do little work in a class and requiring assistance to complete work accurately) and having low mental distress ($P < 0.001$). Low mental distress associated with the attitude of extending material provided in class with other sources, and negatively associated with the belief that the primary goal is to pass class ($P < 0.01$). Interestingly, males and non-minority students in our dataset were more likely to have low mental distress ($P < 0.01$) (Table 2).

3.3b. Mild mental distress as a dependent variable

Remarkably, mild levels of mental distress reflected very few and weaker associations with other variables compared to low and severe mental distress. There was a positive association between mild mental distress and likelihood of neglecting work and family ($P < 0.05$). Mild mental distress negatively correlated with GPA ($P < 0.05$). (Table 3)

Table 1
Participant characteristics. ANOVA and Chi-square.

	Men	Women	P value
Gender	162 (29%)	394(71%)	
Mean Age (Standard Deviation)	20.14 (0.65)	20.10(0.50)	0.36
GPA (Standard Deviation)	3.25(0.40)	3.42(0.38)	0.00**
College standing			
Freshman	17	46	0.51
Sophomore	57	123	
Junior	40	89	
Senior	35	110	
Graduate	13	26	
Race			
AA	5	15	0.63
Caucasian	118	302	
Hispanic	13	23	
Other	26	54	
ADHD meds			
Never or less than once per month	149	382	0.04*
Once per week	10	9	
Once per day	2	2	
2-3 per day	1	1	
Frequency of alcoholic drinking (during one month)			
Non-drinkers occasional (0-2 times)	119	48	0.45
Moderate drinkers (3-6 times)	85	28	
Excessive drinkers (over 7 times)	190	86	
Mental distress			
Low Mental distress	181	91	0.02*
Mild Mental distress	116	47	
Severe Mental distress	97	24	
Greek Life			
Yes	33	81	0.99
No	129	313	

* $P < 0.05$.
** $P < 0.001$.

3.3c. Severe mental distress as a dependent variable

Severe mental distress strongly associated with daytime sleepiness (such as likelihood of falling asleep while performing watching TV ($P = 0.000$), sitting down, talking to someone or after eating lunch) ($P < 0.001$). It also associated with poor academic efforts (such as having an interest in learning ($P < 0.001$) and inversely with the belief that academic performance depends on efforts made as well as critically analyzing concepts presented by teachers) ($P < 0.01$). Interestingly, those who reported no ease in obtaining alcohol drinks are likely to suffer from severe mental distress, which may reflect their age, and hence level of PFC maturity ($P < 0.01$). There was a negative association between severe mental distress and GPA ($P < 0.05$). Finally, females and minority students are more likely to exhibit severe mental distress in our dataset ($P < 0.01$). (Table 4)

3.3d. Low GPA (2.99 and below) as a dependent variable

The most robust correlations with low GPA were linked to the anxiety from failing an exam and requiring assistance to complete work accurately ($P = 0.000$). Low GPA associated with daytime sleepiness (i.e., likelihood of falling asleep while sitting down, as a car passenger, after lunch or laying down, ($P < 0.001$) or while watching TV or talking to someone ($< P < 0.01$)). Low GPA also associated with indicators of substance abuse such as combining NADHD drugs ($P < 0.01$) and drinking alcohol to forget problems ($P < 0.05$). Soft drink consumption positively associated with low GPA as well ($P < 0.001$). A pattern of weak academic performance and attitudes was associated with low GPA (such as wanting to do little work in classes ($P < 0.001$), less likely to extend material provided in class with other sources and less likely to critically analyze concepts that the teachers present ($P < 0.01$)). Low

Table 2
PCR results for low mental distress as a dependent variable.

Low mental distress	Estimate	Std. Error	Df	t value	Pr(> |t|)
Gender	0.0064939	0.0020685	9	3.1394	0.0119389*
Race	−0.007623	0.0030649	9	−2.4874	0.0345720*
Likely to feel sick from drinking	−0.002667	0.0038985	9	−2.0992	0.0652026
Likely to fall asleep while sitting	−0.000529	0.0046018	9	−6.6789	9.069e-05***
Likely to fall asleep while watching TV	−0.030735	0.0046981	9	−5.9431	0.0002172***
Likely to fall asleep as a car passenger	−0.027921	0.0049706	9	−5.2219	0.0005478***
Likely to fall asleep while lying down	−0.025956	0.0041761	9	−6.1077	0.0001776***
Likely to fall asleep while talking to someone	−0.025506	0.0038004	9	−7.1571	5.325e-05***
Likely to fall asleep after a lunch without alcohol	−0.0272	0.0041183	9	−6.6709	9.152e-05***
GPA last semester	−0.027473	0.0040686	9	3.258	0.0098698**
Academic performance depends on efforts I make	0.0132555	0.0025551	9	3.6759	0.0051075**
I think of the consequences of failing during an exam	0.0093926	0.0023686	9	−4.3389	0.0018805**
Primary goal is to pass class	−0.010277	0.0032429	9	−3.1178	0.0123621*
I extend material provided in class with other sources	−0.010111	0.0038459	9	2.9793	0.0154672*
Require assistance to complete work accurately	0.0114581	0.0046039	9	−3.8221	0.0040770**
I critically analyze the concepts that the teachers present	−0.017596	0.0035613	9	3.7354	0.0046581**
Interested learning	0.0133031	0.003593	9	4.1149	0.0026178**
I want to do as little work as I have to in my classes	0.0147846	0.0041372	9	−3.6104	0.0056562**
I minimize my work, If I know I am getting an A in a class	−0.014937	0.0037355	9	−2.2938	0.0474810*
GPA	0.0025011	0.0041006	9	3.6435	0.0053719**

*** $P = 0.000$.
** $P < 0.001$.
* $P < 0.01$; $P < 0.05$.

Table 3
PCR significant results for mild mental distress as a dependent variable. $P < 0.05$.

Mild mental distress	Estimate	Std. Error	Df	t value	Pr (> |t|)
Neglected work or family	0.0084517	0.0044974	9	1.8793	0.09292
GPA	−0.010191	0.0052636	9	−1.9361	0.08484

GPA positively associated with severe ($P < 0.001$) and mild mental distress and ($P < 0.05$) (Table 5).

3.3e. High GPA (3.0 and above) as a dependent variable

High GPA reflected many reverse patterns detected with low GPA. High GPA negatively correlated with daytime sleepiness (i.e. likelihood of falling asleep while sitting down or watching TV ($P = 0.0000$) or while laying down or talking to someone ($P < 0.001$). High GPA associated with good academic performance and attitude such as interest in learning and extending material provided in class with other sources ($P < 0.001$). High GPA did not associate with substance abuse ($P < 0.05$) and positively associated with low mental distress ($P < 0.001$).

4. Discussion

4.1. Summary of the main findings

This paper presents a substantial number of new findings and support reports from the literature. 1) Low mental distress in college students positively associated with GPA, good academic effort, low daytime sleepiness, and less likelihood of substance abuse. 2) Severe mental distress associated with being a minority, poor academic efforts and attitudes, daytime sleepiness and having a hard time obtaining

Table 4
PCR results for severe mental distress as a dependent variable. $P < 0.05$.

Severe mental distress	Estimate	Std. Error	Df	t value	Pr(> |t|)
Gender	−0.015467	0.0054284	9	−2.8493	0.0191099*
Race	0.0195224	0.0069428	9	2.8119	0.0203148*
Ease of obtaining alcoholic beverages	−0.020458	0.0073461	9	−2.7849	0.0212293*
Likely to fall asleep while sitting	0.0651506	0.0138413	9	4.707	0.0011092**
Likely to fall asleep while watching TV	0.0579006	0.0116063	9	4.9887	0.0007505***
Likely to fall asleep as a car passenger	0.0563778	0.0133993	9	4.2075	0.0022811**
Likely to fall asleep while lying down	0.0523957	0.0129387	9	4.0495	0.0028869**
Likely to fall asleep while talking to someone	0.0594514	0.0138927	9	4.2793	0.0020520**
Likely to fall asleep after a lunch without alcohol	0.0578491	0.0146373	9	3.9522	0.0033437**
GPA last semester	−0.025665	0.0117661	9	−2.1812	0.0570590
Academic performance depends on efforts I make	−0.018302	0.0060008	9	−3.05	0.0137925*
I think of the consequences of failing during an exam	0.0233863	0.005776	9	4.0489	0.0028897**
Primary goal is to pass class	0.0209374	0.0098706	9	2.1212	0.0629162
Require assistance to complete work accurately	0.0378827	0.0102592	9	3.6926	0.0049775**
I critically analyze the concepts that the teachers present	−0.024208	0.0094082	9	−2.5731	0.0300345*
Interested learning	−0.028438	0.0068031	9	−4.1802	0.0023754**
I want to do as little work as I have to in my classes	0.0292244	0.0054865	9	5.3266	0.0004768***
GPA	−0.029534	0.0134385	9	−2.1977	0.0555456

*** $P = 0.000$
** $P < 0.001$
* $P < 0.01$.

Table 5
PCR results for low GPA as a dependent variable. $P < 0.05$.

Low GPA	Estimate	Std. Error	Df	t value	Pr(> |t|)
Gender	−0.001585	0.000773	9	−2.0499	0.070625
Race	0.0030796	0.0009925	9	3.1029	0.012663*
Soft drinks	0.0037535	0.0010991	9	3.415	0.007689**
Combining ADHD meds	0.0018293	0.0007358	9	2.486	0.034648*
Drink alcohol to forget problems	0.0066896	0.0034472	9	1.9406	0.084229
Likely to fall asleep while sitting	0.015423	0.0043391	9	3.5544	0.006173**
Likely to fall asleep while watching TV	0.013087	0.0041652	9	3.142	0.01189*
Likely to fall asleep as a car passenger	0.013842	0.0032539	9	4.254	0.00213**
Likely to fall asleep while lying down	0.013273	0.0030639	9	4.3322	0.001899**
Likely to fall asleep while talking to someone	0.005485	0.0019513	9	2.8109	0.020347*
Likely to fall asleep after a lunch without alcohol	0.011182	0.0028949	9	3.8627	0.003831**
GPA last semester	−0.0050664	0.0014992	9	−3.3793	0.008136**
Academic performance depends on efforts I make	−0.0033537	0.0012597	9	−2.6623	0.025948*
I think of the consequences of failing during an exam	0.012167	0.002123	9	5.7311	0.000283***
Primary goal is to pass class	0.014447	0.0037209	9	3.8827	0.003716**
I extend material provided in class with other sources	−0.009339	0.0040986	9	−2.2786	0.048674*
Require assistance to complete work accurately	0.012509	0.0022924	9	5.4569	0.000402***
I critically analyze the concepts that the teachers present	−0.0082092	0.002768	9	−2.9657	0.015813*
Interested learning	−0.010377	0.0034679	9	−2.9923	0.015145*
I want to do as little work as I have to in my classes	0.012781	0.0033018	9	3.8708	0.003784**
I minimize my work, If I know I am getting an A in a class	0.0081365	0.0039585	9	2.0554	0.069994
Severe mental distress	0.014408	0.0033319	9	4.3244	0.001921**
Mild mental distress	0.0016635	0.0009015	9	1.8453	0.09808
Low mental distress	−0.005635	0.0012386	9	−4.5491	0.001388**

*** $P = 0.000$
** $P < 0.001$
* $P < 0.01$.

Table 6
PCR results for high GPA as a dependent variable. $P < 0.05$.

High GPA	Estimate	Std. Error	Df	t value	Pr(> |t|)
Race	−0.006159	0.0022246	9	−2.7686	0.0218021*
Soft drinks	−0.007507	0.0028907	9	−2.597	0.0288814*
Combining ADHD meds	−0.003659	0.0016515	9	−2.2154	0.0539716
Drink alcohol to forget problems	−0.013379	0.0070497	9	−1.8978	0.0902005
Likely to fall asleep while sitting	−0.030846	0.0061667	9	−5.002	0.0007369***
Likely to fall asleep while watching TV	−0.026174	0.0042016	9	−6.2295	0.0001533***
Likely to fall asleep as a car passenger	−0.027684	0.0060275	9	−4.5929	0.0013037**
Likely to fall asleep while lying down	−0.026546	0.0055805	9	−4.757	0.001034**
Likely to fall asleep while talking to someone	−0.01097	0.0032953	9	−3.3291	0.0088123**
Likely to fall asleep after a lunch without alcohol	−0.022364	0.004772	9	−4.6866	0.0011416**
GPA last semester	0.010133	0.0035601	9	2.8462	0.0192078*
Academic performance depends on efforts I make	0.0067074	0.003388	9	1.9797	0.0790952
I think of the consequences of failing during an exam	−0.024334	0.0089953	9	−2.7052	0.0241873*
Primary goal is to pass class	−0.028894	0.0112	9	−2.5798	0.0297074*
I extend material provided in class with other sources	0.018678	0.0052953	9	3.5273	0.0064414**
Require assistance to complete work accurately	−0.025019	0.0067311	9	−3.7169	0.0047935**
I critically analyze the concepts that the teachers present	0.016418	0.0053794	9	3.0521	0.0137469*
Interested learning	0.020753	0.0059396	9	3.4941	0.0067864**
I want to do as little work as I have to in my classes	−0.025561	0.0055985	9	−4.5657	0.0013552**
I minimize my work, If I know I am getting an A in a class	−0.016273	0.0052283	9	−3.1125	0.0124685*
Severe mental distress	−0.028817	0.011882	9	−2.4253	0.0382783*
Low mental distress	0.011269	0.002717	9	4.1476	0.0024932**

*** $P = 0.000$
** $P < 0.001$
* $P < 0.01$.

alcoholic beverages, which we hypothesize as reflective of the youngest age bracket. 3) Low GPA associated with mental distress, daytime sleepiness, poor academic attitude and risky behaviors 4) High GPA correlated with good academic efforts, less daytime sleepiness and likelihood of engaging in risky behaviors, and low mental distress.

4.2. Significance of findings

There are several significances that are worth discussing. Our findings add novel pieces to the puzzle that tie diverse levels of mental distress to daytime sleepiness, academic attitude, GPA and substance abuse. Daytime sleepiness is potentially indicative of a low sleep quality. The amalgamation of variables that associate with GPA, to our knowledge, is original too. Our results indicate that in many instances manageable lifestyle factors may affect mental wellbeing in college students. Likewise, mental health, academic efforts and maladaptive coping mechanisms may affect GPA. Many of our findings were reported previously in the literature. Shippee and Owens [36] described an association between GPA, depression and alcohol drinking using longitudinal high school data. Low GPA has been linked to nonmedical ADHD drug use and associated with a poor sleep quality [37]. Additionally, alcohol use among college students correlated with a poor sleep quality and a lower GPA [38].

Considering our results collectively, these findings may be reflecting a trajectory of neurochemical and neuroanatomical alterations that associate with mental health decline and poor academic performance in young adults. Students with low mental distress had a positive attitude toward learning, reported less daytime sleepiness, had a high GPA and were less likely to abuse substances. Those who had mild levels of mental distress reflected a slight decline in academic performance. On the other hand, there were many stronger correlations between severe mental distress and poor academic attitudes, low GPA and daytime sleepiness. This change in the direction of associations may reflect the neuroanatomical alterations triggered by lifestyle factors, that contribute to mental distress.

Interestingly, mental distress and GPA closely associated with substance abuse. Substance abuse may alter mental health as well and may arise as maladaptive coping mechanisms. In both instances, the risk for dependence and addiction is high [46]. Abuse of nonmedical ADHD (NADHD) medications, as "study" drugs, among college students is on the rise [47]. These psychostimulants are typically prescribed to individuals with symptoms of ADHD to boost brain dopamine levels. Besides supporting concentration and movement, dopamine is also associated with motivation and pleasurable feelings attributable to its effect on the brain reward system. However, abusers may experience dopamine surge that is often similar in magnitude to the one triggered by illicit drug use [48]. The sudden rise in dopamine levels causes an initial sense of wellbeing, which makes these drugs attractive for further use. Substances that alter the brain reward system chemistry are likely to cause dependence and prime the brain for further substance abuse [46]. Consequently, these drugs may become a stipulation for users. This risky behavior has been associated with poor PFC maturation in young adults, cognitive impairment, mental health decline and a risk for addiction, as these drugs modify the normal activity of the brain [49–52].

In fact, the brain adapts by shifting the natural motivational circuitry, which involves major structural changes and genomic responses [53]. Consequently, the re-wiring of the circuit leads to loss of response to biological stimuli and induces behavioral changes [54]. Repeated use induces neuroplasticity that transition individuals from social drug use to abuse and compulsive seeking [55]. Therefore, students who occasionally use alcohol or NADHD may be setting the stage for further substance abuse and dependence. Consequently, mental health and cognitive abilities are significantly affected.

5. System dynamic (SD) modeling

Next, our aim was to describe the sequential events that potentially explain the neurochemical and neuroanatomical changes that lead to virtuous or vicious cycles to support or undermine mental health and academic performance. An SD model was built to illustrate the integration of the different variables discussed. Since the current study in observational in nature, we hypothesized possible causal pathways among various factors that have possibly led to the results we observed in this study. Therefore, further experiments and simulation studies are needed to verify these hypothetical models. In addition, some of the variables displayed in the models (neurotransmitters, neuroanatomy, diet, inflammation, and HC functioning) were not measured in this study but were based on evidences from the literature. Therefore, the hypothetical model combines previous findings from our laboratory, current results and evidence from the literature. Our model describes many sub-sets of reinforcing loops that strengthen the connection between the different part of the system. (Fig. 1). The bolded arrows refer to current and previous findings from our laboratory, while simple arrows refer to evidence in the literature.

5.1. Modeling the hypothetical causal loops in mental distress

College students tend to have poor dietary habits, which induce a low-grade inflammation and alter neurotransmission. Due to poor PFC maturity, young college students are less likely to handle psychological stressors associated with college life, relationships and academic pressures. Consequently, mental distress adds to the biochemical imbalance that disrupts CLC communication. As a Result, HC dysregulation leads to a decline in mood, motivation and learning, which prompt some students to use substances to increase dopamine levels and boost mental wellbeing. Substance of abuse disrupts the circadian rhythm, which is critical for memory consolidation and hippocampal neurogenesis [27,56] and may further affect diet quality. Consequently, these homeostatic disturbances set the stage for a potential neurocircuitry rewiring and hippocampal structural damage with repeated use. Thus, mood, motivation level, and cognitive functions among others are disturbed. The drug-induced hippocampal changes stimulate further drug seeking. The decline in mood and academic performance leads to further abuse of NADHD drugs. Low mood stimulates further unhealthy eating. A vicious circle of mental distress, substance abuse, daytime sleepiness and cognitive deficit may arise (Reinforcing Loops R3 to R7 of Fig. 1). (Table 7).

5.2. Modeling the hypothetical causal loops in mental wellbeing

Many reports in the literature link consumption of a healthy diet to mental wellbeing [24,57,58]. Additionally, low mental distress associates with a motivation to further improve healthiness [24]. Therefore, we hypothesized that those with low mental distress follow a healthy diet and lifestyle. A healthy diet optimizes brain chemicals and maintains a positive mood by supporting the integrity of brain structures and keeping inflammation at bay. Consequently, a positive mood increases motivation and supports academic efforts. A positive feedback loop sets-off to further reinforce motivation and positive mood states. The latter stimulates hippocampal neurogenesis, which supports cognitive functions and improves GPA (depicted by the virtuous cycles Loop R1 and R2 of Fig. 1).

6. Strengths and limitation of the study

The study has many strengths. The use of PCR, a robust multivariate analysis, to identify the latent variables of significance increases the validity of the findings. Additionally, the study provides novel conclusions that fill many gaps in the literature. In addition, using an SD modeling approach to depict the progression of physiological and neurobehavioral events adds to the strength of the study. The large sample size, which includes students form different colleges across the US is another strength. Nevertheless, the study has few limitations. The study is cross-sectional and may not represent the dynamicity of mental distress in relation to the other variables. The convenience sample is also a limitation, which may not represent the college population at large. The fact that high GPA and no substance abuse were significant in our data may have skewed the results, nevertheless evidence of substance abuse with low GPA was still detectable. Finally, no actual measurements of several variables included in the models were collected.

7. Implication for future research

Validation of the hypothetical causalities included in the SD model is needed. In addition, dietary interventions with neuroimaging studies are needed to assess the degree of neurochemical and neuroanatomical alterations associated with mental distress and substance abuse. Additionally, since exercise may potentially stimulate hippocampal neurogenesis and improve mood, structured physical activity may have the potential to reverse some of the negative behaviors discussed in this study.

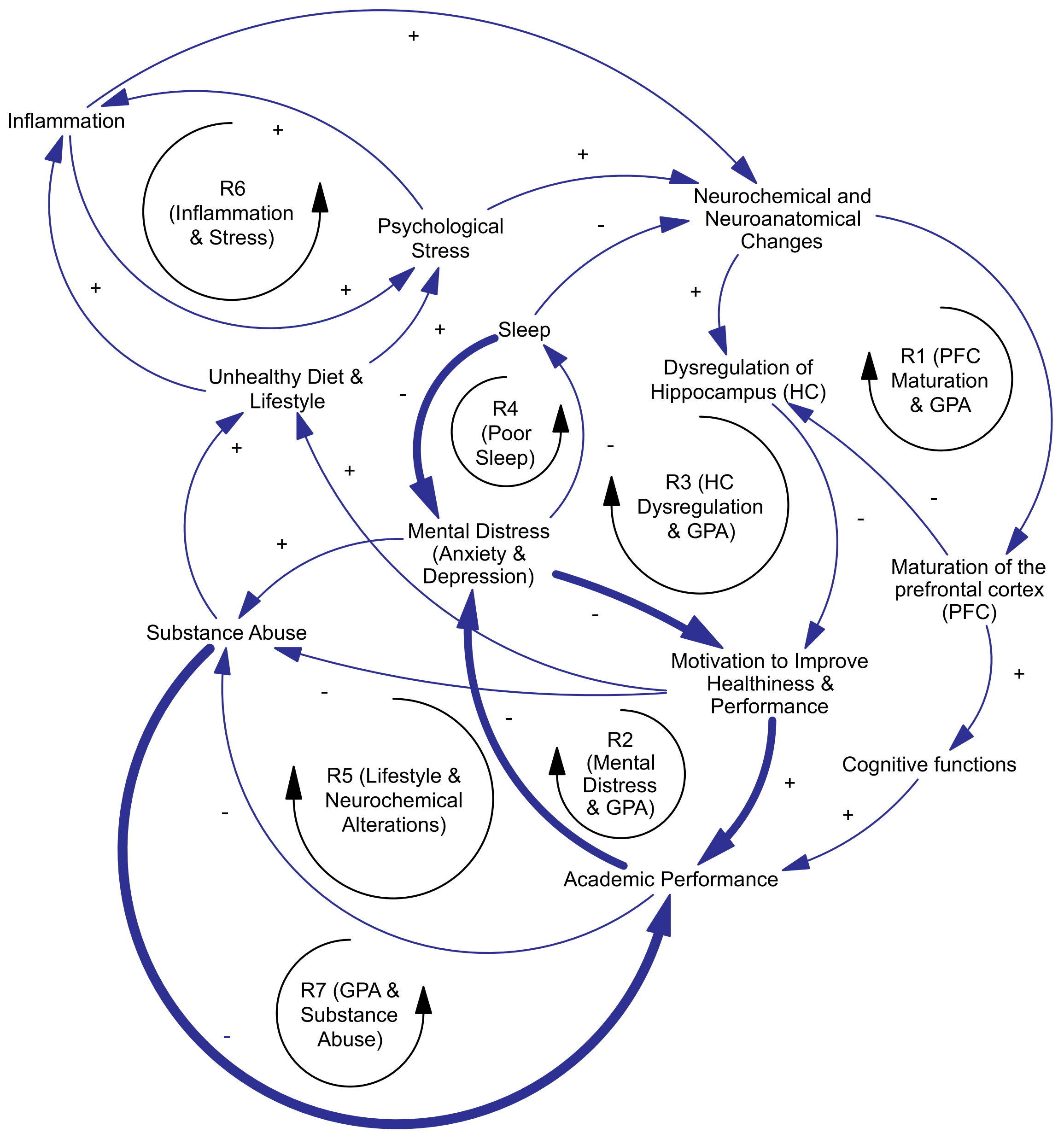

Fig. 1. System Dynamic Model explaining the integration of variables. Evidence from the literature Current Findings.

Table 7
Description of the reinforcing loops of the System Dynamic Model.

Loop Name	Components
R1 (PFC Maturation & GPA)	Mental Distress (Anxiety & Depression) → Sleep → Neurochemical and Neuroanatomical Changes → Maturation of the prefrontal cortex (PFC) → Cognitive functions→ Academic Performance →Mental Distress (Anxiety & Depression)
R 2 (Mental Distress & GPA)	Mental Distress (Anxiety & Depression) → Motivation to Improve Healthiness & Performance → Academic Performance → Mental Distress (Anxiety & Depression)
R3 (HC Dysregulation & GPA)	Mental Distress (Anxiety & Depression) → Sleep → Neurochemical and Neuroanatomical Changes → Dysregulation of Hippocampus (HC) → Motivation to Improve Healthiness & Performance→ Academic Performance →Mental Distress (Anxiety & Depression)
R4 (Poor Sleep)	Mental Distress (Anxiety & Depression) → Sleep → Mental Distress (Anxiety & Depression)
R5 (Lifestyle & Neurochemical Alterations)	Unhealthy Diet & Lifestyle → Psychological Stress→ Neurochemical and Neuroanatomical Changes →Maturation of the prefrontal cortex (PFC) → Cognitive functions (PFC) →Academic Performance →Substance Abuse→ Unhealthy Diet & Lifestyle
R6 (Inflammation & Stress)	Inflammation → Psychological Stress→ Inflammation
R7 (GPA & Substance Abuse)	Substance Abuse → Academic Performance → Substance Abuse

8. Conclusion

Our results suggest that insalubrious, but manageable, lifestyle factors contribute to mental health in college students. The cycle of events eventually impacts academic performance. Additionally, our findings describe the potential progression of neurobehavioral alterations associated with mental distress that may explain poor academic performance and risk of substance abuse in college students. These neurobehaviors may be reflecting cellular and molecular changes in the brain that could be potentially long-lasting.

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Conflict of interest

The authors declare that there is no conflict of interest.

Ethical statement

The study protocol was reviewed and approved by the Internal Review Board (IRB) at Binghamton University. The IRB ensures that the work is carried out in accordance with the Code of Ethics of the World Medical Association.

Authorship

Author 1 designed the study and wrote the manuscript, author 2 and author 3 analyzed the data and built the model, authors 4 and 5 carried it out the experimental work and data collection.

Supplementary materials

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References

[1] A. Eiser, The crisis on campus, Am. Psychol. Assoc. 42 (2011) 18–19.
[2] National Alliance on Mental Illness. 2019. Available at : https://www.nami.org/Learn-More/Mental-Health-By-the-Numbers.
[3] R.P. Gallagher, National Survey of Counseling Center Directors, American College Counseling Association (ACCA), University of Pittsburgh, Pennsylvania, 2010, pp. 1–63.
[4] S. Ducharme, M.D. Albaugh, J.J. Hudziak, K.N. Botteron, T. Nguyen, C. Truong, et al., Anxious/depressed symptoms are linked to right ventromedial prefrontal cortical thickness maturation in healthy children and young adults, Cereb. Cortex 24 (2014) 2941–2950.
[5] K. Li, E. Xu, The role and the mechanism of γ-aminobutyric acid during central nervous system development, Neurosci. Bull 24 (2008) 195–200.
[6] B.S McEwen, C. Nasca, J.D Gray, Stress effects on neuronal structure: hippocampus, amygdala, and prefrontal cortex, Neuropsychopharmacol. Offi. Public. Am. Coll. Neuropsychopharmacol. 41 (2016) 3–23.
[7] M. Arain, M. Haque, L. Johal, P. Mathur, W. Nel, A. Rais, et al., Maturation of the adolescent brain, Neuropsych. Disea. Treat. 9 (2013) 449–461.
[8] S.P. Farris, R.A. Harris, I. Ponomarev, Epigenetic modulation of brain gene networks for cocaine and alcohol abuse, Front. Neurosci. 9 (2015) 176.
[9] S. Lolak, P. Suwannarat, R.H. Lipsky, Epigenetics of depression, Prog. Mol. Biol. Transl. Sci. 128 (2014) 103–137.
[10] M.A. Schiele, K. Domschke, Epigenetics at the crossroads between genes, environment and resilience in anxiety disorders, Genes, Brain Behav. 17 (2018) e12423.
[11] J. Seo, J. Wei, L. Qin, Y. Kim, Z. Yan, P. Greengard, Cellular and molecular basis for stress-induced depression, Mol. Psychiatry 22 (2017) 1440–1447.
[12] S.W. Cole, M.R. Irwin, Reciprocal regulation of the neural and innate immune systems, Nat. Rev. Immunol. 11 (2011) 625–632.
[13] M. BoldrinI, C.A. Fulmore, A.N. Tartt, L.R. Simeon, I. Pavlova, V. Poposka, et al., Human Hippocampal Neurogenesis Persists throughout Aging, Cell Stem Cell 22 (2018) 599 e5.
[14] S.F. Sorrells, M.F. Paredes, A. Cebrian-Silla, K. Sandoval, D. Qi, K.W. Kelley, et al., Human hippocampal neurogenesis drops sharply in children to undetectable levels in adults, Nature 555 (2018) 381 R.
[15] T. Toda, S.L. Parylak, S.B. Linker, F.H. Gage, The role of adult hippocampal neurogenesis in brain health and disease, Mol. Psychiatry 24 (2019) 67–87.
[16] I. Koyanagi, K.G. Akers, P. Vergara, S. Srinivasan, T. Sakurai, M. Sakaguchi, Memory consolidation during sleep and adult hippocampal neurogenesis, Neur. Regen. Res. 14 (2019) 20–23.
[17] H.J. Krugers, P.J. Lucassen, H. Karst, M. Joëls, Chronic stress effects on hippocampal structure and synaptic function: relevance for depression and normalization by anti-glucocorticoid treatment, Front. Synap. Neurosci. 2 (2010) 24.
[18] B.S. McEwen, Stress and hippocampal plasticity, Annu. Rev. Neurosci. 22 (1999) 105–122.
[19] R.S. Duman, Structural alterations in depression: cellular mechanisms underlying pathology and treatment of mood disorders, CNS Spectr. 7 (2002) 140–147.
[20] A.H. Miller, V. Maletic, C.L. Raison, Inflammation and its discontents: the Role of Cytokines in the Pathophysiology of Major Depression, Biol. Psychiatry 65 (2009) 732–741.
[21] A.H. Miller, C.L. Raison, The role of inflammation in depression: from evolutionary imperative to modern treatment target, Natu. Rev. Immunol.. 16 (2016) 22–34.
[22] A.M. Myint, Y.K. Kim, Cytokine–serotonin interaction through IDO: a neurodegeneration hypothesis of depression, Med. Hypotheses 61 (2003) 519–525.
[23] J.C Felger, The role of dopamine in inflammation-associated depression: mechanisms and therapeutic implications, Curr. Top. Behavi. Neurosci. 31 (2007) 199.
[24] L. Begdache, M. Chaar, N. Sabounchi, H. Kianmehr, Assessment of dietary factors, dietary practices and exercise on mental distress in young adults versus matured adults: a cross-sectional study, Nutr Neurosci. (2017) 1–11.
[25] F.N. Jacka, N. Cherbuin, KJ Anstey, P Sachdev, P. Butterworth, Western diet is associated with a smaller hippocampus: a longitudinal investigation, J. Aus. Coll. Nutr. Environ.l Med. 35 (2016) 11–17.
[26] P. Kalyan-Masih, J.D. Vega-Torres, C. Miles, E. Haddad, S. Rainsbury, M. Baghchechi, et al., Western high-fat diet consumption during adolescence increases susceptibility to traumatic stress while selectively disrupting hippocampal and ventricular volumes, eNeuro. 3 (2016) 1–24.
[27] R. Guzman-Marin, T. Bashir, N. Suntsova, R. Szymusiak, D. McGinty, Hippocampal neurogenesis is reduced by sleep fragmentation in the adult rat, Neuroscience 148 (2007) 325–333.
[28] M.J. Thomas, P.W. Kalivas, Y. Shaham, Neuroplasticity in the mesolimbic dopamine system and cocaine addiction, Br. J. Pharmacol. 154 (2008) 327–342.
[29] V. Dunn, I.M. Goodyer, Longitudinal investigation into childhood and adolescence-onset depression: psychiatric outcome in early adulthood, Br. J. Psych. 188 (2006) 216–222.
[30] A. Topiwala, C.L. Allan, V. Valkanova, E. Zsoldos, N. Filippini, C. Sexton, et al., Mild alcohol consumption as risk factor for adverse brain outcomes and cognitive decline: longitudinal cohort study, BMJ 357 (2017) j2353.
[31] G.F. Koob, A.J. Roberts, G. Schulteis, L.H. Parsons, C.J. Heyser, P. Hyytia, et al., Neurocircuitry targets in ethanol reward and dependence, Alcohol. Clin. Exper. Res. 22 (1998) 3–9.
[32] D. Nutt, S. Wilson, L. Paterson, Sleep disorders as core symptoms of depression, Dialog. Clin. Neurosci. 10 (2008) 329–336.
[33] T.A. Mellman, Sleep and Anxiety Disorders, Sleep Med. Clin. 3 (2008) 261–268.
[34] S.E. Morris, B.N. Cuthbert, Research Domain Criteria: cognitive systems, neural circuits, and dimensions of behavior, Dialog. Clin. Neurosci. 14 (2012) 29–37.
[35] I. Koyanagi, K.G. Akers, P. Vergara, S. Srinivasan, T. Sakurai, M. Sakaguchi, Memory consolidation during sleep and adult hippocampal neurogenesis, Neu. Regen. Res. 14 (2019) 20–23.
[36] N.D. Shippee, T.J. OwensGPA, Depression, and drinking: a longitudinal comparison of high school boys and girls, Sociol. Perspect. 54 (2011) 351–376.
[37] M.M. Clegg-Kraynok, A.L. McBean, H.E. Montgomery-Downs, Sleep quality and characteristics of college students who use prescription psychostimulants nonmedically, Sleep Med. 12 (2011) 598–602.
[38] J. Singleton, A. Royce, A.R. Wolfson, Alcohol consumption, sleep, and academic performance among college students, J. Stud. Alcoh. Drugs 70 (2009) 355–363.
[39] H.F. Kaiser, An index of factorial simplicity, Psychometrika 39 (1974) 31–36.
[40] M.S. Bartlett, Tests of significance in factor analysis, Br. J. Psychol. 3 (1950) 77–85.
[41] M.J. Azur, E.A. Stuart, C. Frangakis, P.J Leaf, Multiple imputation by chained equations: what is it and how does it work? Int. J. Methods Psychiatr. Res. 20 (2011) 40–49.
[42] J. Fox, S. Weisberg, An R companion to Applied Regression, Sage Publications, California, 2010.
[43] W.F. Massy, Principal components regression in exploratory statistical research, J. Am. Statist. Assoc. 60 (1965) 234–256.
[44] A.M. Krynen, D. Osborne, I.M. Duck, C.A. Houkamau, C.G Sibley, Measuring psychological distress in New Zealand: item response properties and demographic differences in the Kessler-6 screening measure, NZ. J. Psychol. 42 (2013) 69–83.
[45] T. Kuther, The Role of GPA in graduate school admissions, ThoughtCo (2018) Available at https://www.thoughtco.com/gpa-role-in-graduate-school-admissions-1685863.
[46] E.J. Nestler, Is there a common molecular pathway for addiction? Nat. Neurosci. 8 (2005) 1445–1449.
[47] S.E. McCabe, J.R. Knight, C.J. Teter, H. Wechsler, Non-medical use of prescription stimulants among US college students: prevalence and correlates from a national survey, Addiction 100 (2005) 96–106.
[48] S.E. Lakhan, A. Kirchgessner, Prescription stimulants in individuals with and without attention deficit hyperactivity disorder: misuse, cognitive impact, and adverse effects, Brain and Behav, 2 (2012) 661–677.
[49] J.C. Skogen, B. Sivertsen, A.J. Lundervold, K.M. Stormark, R. Jakobsen, M. Hysing, Alcohol and drug use among adolescents: and the co-occurrence of mental health problems. Ung@hordaland, a population-based study, BMJ open 4 (2014) e005357.

[50] R.J. Tait, A. Mackinnon, H. Christensen, Cannabis use and cognitive function: 8-year trajectory in a young adult cohort, Addiction 106 (2011) 2195–2203.
[51] F.T. Crews, C.A. Boettiger, Impulsivity, frontal lobes and risk for addiction, Pharmacol. Biochem. Behav. 93 (2009) 237–247.
[52] A. Noronha, C. Changhai, A.H. Robert, J.C. Crabbe, Neurobiology of Alcohol Dependence, Academic Press, US, 2014.
[53] N.D. Volkow, G. Wang, J.S Fowler, D. Tomasi, F. Telang, R. Baler, Addiction: decreased reward sensitivity and increased expectation sensitivity conspire to overwhelm the brain's control circuit, Bioessays 32 (2010) 748–755.
[54] M. Diana, C. Bolloni, M. Antonelli, D. Di Giuda, F. Cocciolillo, L. Fattore, et al., Repetitive transcranial magnetic stimulation: re-wiring the alcoholic human brain, Alcohol 74 (2019) 113–124.
[55] T.J. Aitken, V.Y. Greenfield, K.M. Wassum, Nucleus accumbens core dopamine signaling tracks the need-based motivational value of food-paired cues, J. Neurochem. 136 (2016) 1026–1036.
[56] D. Chaudhury, L.M. Wang, C.S. Colwell, Circadian regulation of hippocampal long-term potentiation, J. Biol. Rhythms 20 (2005) 225–236.
[57] L. BegdacheCognitive Decline and Mental Distress, A potential mismatch between the contemporary diet and the evolved brain, Anthropol. Ethnol. Open Acc. J. 1 (2018) 1–9.
[58] M. Luciano, J. Corley, S. Cox, M. Valdés Hernández, L. CraiG, D. Dickie, et al., Mediterranean-type diet and brain structural change from 73 to 76 years in a Scottish cohort, Neurology 88 (2017) 449–455.