Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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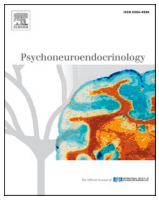

When asking 'are you stressed?' is not enough: Hair cortisol, subjective stress, and alcohol use during the first year of the pandemic

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ABSTRACT

The onset of the COVID-19 pandemic was accompanied by an increase in alcohol use in a third of the population worldwide. To date, the literature shows that subjective reports of stress predicted increased alcohol use during the early stages of the pandemic. However, no studies have investigated the effect of physiological stress (via the stress hormone cortisol) on alcohol use during the pandemic. This study aimed to identify the predictive value of cortisol and/or subjective stress on alcohol use during the first year of the pandemic. Every three months, between June 2020 and March 2021, 79 healthy adults (19–54 years old) answered online questionnaires assessing alcohol use. In May 2020, participants reported pre-pandemic alcohol use, while in June 2020, participants reported current alcohol use, subjective stress measures, and provided a 6 cm hair sample. The latter allowed us to quantify the cumulative levels of cortisol produced in the three months prior to and following the start of the mandatory lockdown measures in March 2020 in Quebec, Canada. A relative change in hair cortisol was computed to quantify the physiological stress response. While controlling for sex, age, and psychiatric diagnoses, multilevel linear regressions revealed that alcohol use increased only among people with concomitant high subjective stress *and* elevated hair cortisol concentrations. Moreover, this increased alcohol use remained elevated one year later. This study documents the importance of simultaneously considering stress biomarkers and subjective stress to identify people at risk of increasing their alcohol use during major stressful life events.

1. Introduction

Alcohol use is the leading risk factor worldwide for premature death and invalidity among people aged 15–49 (Griswold et al., 2018). Further, alcohol is the most abused substance and is associated with the greatest societal burden, costing approximately $249 billion each year in the United States (Sacks et al., 2015). Similar costs per capita have been identified in other countries such as Canada, France, and Germany (Manthey et al., 2021). Evidence shows that under stressful circumstances (e.g., the aftermath of natural disasters or economic adversity), alcohol use changes (Gonçalves et al., 2020). On March 11th, 2020, the World Health Organization declared COVID-19 a pandemic, emphasizing the threat of health complications or death for everyone worldwide. Mandatory lockdowns, as well as restaurant and gym closures, are examples of the drastic measures implemented during this period that impacted our lifestyles (Shimpo et al., 2022). Indeed, studies showed that sanitary measures imposed changes on how, when, and where alcohol was consumed (Hardie et al., 2022; Mangot-Sala et al., 2022).

Some studies have reported numbers as high as 50 % of the population who changed (either increased or decreased) their alcohol use

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after the onset of the pandemic, with 10–30 % increasing their consumption (Shimpo et al., 2022). Thus far, studies mostly described the changes in alcohol use during the early pandemic, which was necessary to rapidly inform governments about this risky health behavior. Now, there is a need to monitor how alcohol use changed in the later stages of the pandemic (Schmidt et al., 2021) and identify the underlying mechanisms driving this change (Kilian et al., 2022). Individuals reported that one of their most common motives behind drinking during the pandemic was to cope with stress (Bramness et al., 2021; Vanderbruggen et al., 2020). This suggests that stress might be a potent factor contributing to increased alcohol use during the pandemic.

According to a recent review on pandemic substance use, 10 studies found a significant association between alcohol use and stress, whereas only two found no association (Schmidt et al., 2021). However, a limitation of the current literature lies in the operationalization of stress as a unifactorial construct, where solely self-report measures of stress were used to predict alcohol use during the pandemic. Yet, the stress response is a complex psychoneuroendocrinological process characterized by the subjective psychological experience of stress and physiological responses (Epel et al., 2018). The subjective stress response consists of ruminative cognitions (Ottaviani et al., 2016), affective states, and emotional reactivity (Epel et al., 2018), while the physiological stress response is composed of two principal systems: the fast-reacting sympathetic nervous system and slow-reacting hypothalamic-pituitary-adrenal (HPA) axis (Joëls and Baram, 2009). As cortisol (the end-product of the HPA axis) can cross the blood-brain barrier to modulate brain activity and influence behavior, this axis has received considerable attention as a mediator of stress-related substance abuse (Koob et al., 1993; McEwen, 2008).

Stressor exposure (i.e., the stressor) and stress response are terms that cannot be used interchangeably (Epel et al., 2018). Indeed, the stress response to a given stressor is subject to great inter-individual variability (Zänkert et al., 2019). These operationalization inconsistencies in the current literature overlook the multifactorial nature of stress and hinder proper conclusions about the impact of stress on alcohol use (Crosswell and Lockwood, 2020; Epel et al., 2018). In sum, beyond assessing pandemic-related stressors, studying the stress response may provide insight into the role of stress on alcohol use during the pandemic. Recent methods allow researchers to measure cumulative levels of stress hormones in hair samples. Given that hair grows 1 cm per month, assessment of various lengths of hair can provide information on periodic variations of cortisol over an extended period of time (Dettenborn et al., 2012). Therefore, researchers can use hair cortisol concentrations (HCC) to retrospectively infer long-term HPA axis activity during the COVID-19 pandemic (Stalder and Kirschbaum, 2012).

Early models that aimed to explain the relationship between stress and alcohol use (e.g., tension-reduction) mainly focused on the reinforcing property of alcohol at modulating stress-related affective states. Consequent to recent neuroendocrinological advances in the stress response and alcohol use, newer models designate the physiological stress system as a key mediator of increased alcohol intake (Koob et al., 1993; Koob and Schulkin, 2019). Under stress, the brain simultaneously activates the HPA axis and dopaminergic reward circuitry, which is necessary to encode the value and context of a stressor (Blaine and Sinha, 2017). These systems are also involved in reinforcement learning, such as learning to use alcohol as a coping mechanism (Koob and Schulkin, 2019). Moreover, alcohol-related increases in HPA axis activity are associated with the subjective "high" state induced by alcohol (Blaine and Sinha, 2017). However, chronically stressed individuals show a blunted stress response to alcohol intake, thus requiring greater alcohol volumes to achieve the same "high". Taken together, alcohol use and the HPA axis show a complex bidirectional relationship: higher cortisol levels are associated with increased motivation to consume alcohol and alcohol use directly stimulates the HPA axis, ultimately producing more cortisol.

Although multiple reports suggest that subjective stress was related to alcohol use during the pandemic (Schmidt et al., 2021), no studies have assessed the role of the physiological stress response. Yet, a wealth of literature suggests that subjective and physiological measures of stress are not always correlated (Campbell and Ehlert, 2012; Hjortskov et al., 2004; Lupien et al., 2022). Therefore, to better understand the role of the stress response on alcohol use during the pandemic, it is essential to assess both subjective and physiological stress measures.

1.1. Objectives

The objectives of this study were to 1) longitudinally describe how alcohol use changed in the year following the first pandemic-related lockdown in Quebec, Canada and 2) determine whether HCC and subjective stress experienced during the first lockdown have an independent or cumulative predictive value on alcohol use up to one year later. It was hypothesized that each factor would individually contribute to increased alcohol use during the first lockdown. However, given the lack of studies investigating both systems (subjective and physiological), it was impossible to hypothesize whether the combination of HCC and subjective stress would be a better model to explain increased alcohol use. We also had no predictions about the durability of the effect.

2. Materials and methods

2.1. Participants

Participants were recruited for this study following their participation in one of our laboratory-based experiments that took place between 2017 and 2019. These experiments aimed to study the effect of stress on fear conditioning (unpublished data) and observational fear learning within families (for further details on the purpose of the study, methods used, and obtained results, see Marin et al., 2020). For these laboratory-based experiments, parent-child dyads and young adults were recruited through advertisements on social media and posters in the surroundings of the research center. Participants were extensively screened to ensure that they had no health-related conditions that could affect their HPA axis (e.g., physical illnesses, past and/or present psychiatric disorders, and medication use). Of the 232 adults contacted, 156 (107 women; 68.59 %) adults aged 19–54 (M = 34.43, SD = 9.86) agreed to participate in the current study (67.24 %). However, only participants who 1) reported drinking at least at one timepoint and 2) consented to and could provide enough hair to get the full 6 cm hair sample (see *Hair sample collection* section) were kept for the main analyses. Therefore, our final sample was composed of 79 adults (67 women; 84.81 %) aged 19–54 (M = 35.09 years, SD = 9.53). No a priori power analysis could be performed as this study emerged from a larger project for which past participants were recontacted during the first lockdown of the pandemic to take part in this COVID-related study. Therefore, the sample size for the current manuscript was completely dependent on three main conditions that were dictated by our research question: 1) participants gave their consent to take part in this longitudinal COVID-19 study; 2) participants had to report that they consume alcohol; and 3) participants were able to provide a 6 cm hair sample. No post-hoc power analysis was conducted as this has been discouraged in the literature (Gelman, 2019; Lakens, 2022; Levine and Ensom, 2001). To compensate for the relatively small sample size and absence of a priori power analyses, we ensured the reliability and robustness of our results by conducting bootstrap analyses for coefficients and confidence intervals (see Section 2.4 below).

2.2. Measures

2.2.1. Alcohol use

Participants were asked to report their weekly alcoholic beverage consumption in the past three months. They also had to report if their alcohol use changed (increased, decreased, or stayed the same) since the

first COVID-19 lockdown in Canada.

2.2.2. Reasons for increasing or decreasing alcohol use

The questionnaire used to assess reasons for increasing or decreasing alcohol use was based on a questionnaire developed by Educ'Alcool (www.educalcool.qc.ca/), an independent non-profit organization that implements prevention and education programs on alcohol use in Quebec. Participants who reported that their alcohol use increased or decreased since the first COVID-19 lockdown were asked to choose one or multiple reasons from a provided list. This questionnaire was used for descriptive purposes only and to inform the reader about the motives of alcohol use in our sample. However, it is important to note that it is not a validated research questionnaire.

2.2.3. Perceived Stress Scale (PSS)

The French version of the PSS (Lesage et al., 2012) is a 14-item self-report scale used to assess "the degree to which situations in one's life are appraised as stressful" (Cohen et al., 1983). Participants must indicate how often they felt or thought a certain way in the last month using a Likert scale ranging from 0 (never) to 4 (very often). The total score ranged from 0 to 56. The higher the score, the more stress the individual perceived in the last month. The validated French version of the PSS has an internal consistency of.84 (Lesage et al., 2012).

2.2.4. Past and current psychiatric disorders

Psychiatric disorders have the potential to alter HPA axis activity and HCC (Baumeister et al., 2014; Koumantarou Malisiova et al., 2021). Therefore, we controlled for the presence of such diagnoses. Participants were asked if they had a past or current diagnosis of psychiatric disorders (assessed by a health care professional) and were instructed to answer either "yes" or "no".

2.3. Procedure

2.3.1. Completion of questionnaires

In May 2020 (T0), participants were asked to retrospectively report their weekly alcoholic beverage consumption before the start of the pandemic. In June 2020 (T1; first trimester of the pandemic), participants completed the PSS, self-collected a hair sample, answered questions regarding past or current psychiatric disorders, reported their current weekly alcohol consumption, changes in their alcohol use and if appropriate, reasons why they increased or decreased their alcohol use since the first COVID-19 related lockdown (March 23rd, 2020). Participants also had to answer questions about their weekly alcohol use in September 2020 (T2; second trimester of the pandemic), December 2020 (T3; third trimester of the pandemic), and March 2021 (T4; one year into the pandemic). All questionnaires were completed via Qualtrics, an online-based and highly secure platform. To access the platform, a personalized URL link was sent to each participant via email at each study timepoint.

2.3.2. Hair sample collection

Studies show that home-based self-collection of hair samples is a valid method to measure HCC (Enge et al., 2020; Ouellet-Morin et al., 2016). Therefore, in June 2020 (T1), participants received the material needed to collect hair samples at home (i.e., written instructions with corresponding pictures, hemostatic scissors and pincer, hair clamps, a plastic bag, an envelope, adhesive tape, and a piece of cardboard that resembled a ruler), along with a detailed explanatory video on how to provide a valid sample. They were asked to provide a sample of 6 cm in length. This allowed us to analyze two 3 cm segments using the same hair sample. As hair grows an average of 1 cm per month (Stalder and Kirschbaum, 2012), each segment (segment A and segment B) should represent a retrospective period of HPA axis activity of approximately three months. Segment A represents hair growth from mid-December 2019 to mid-March 2020, which corresponds to the period preceding the start of the first wave of COVID-19 in Canada. Segment B represents hair growth from mid-March 2020 to mid-June 2020, which corresponds to the first trimester of the pandemic and the first lockdown in Quebec, Canada.

Participants were instructed to collect their hair samples from the occipital region of their heads. To collect the sample, they first had to comb their hair to separate a section of at least 1 cm in width. To make sure the section was held in place, they had to place a hair clamp 1 cm from the scalp. To ensure that the sample was sufficiently long (6 cm in length), participants were told to place their sample on a piece of cardboard (that resembled a ruler), with multiple lines that were separated by 1 cm. Once they had a sample of sufficient length, they were instructed to cut the section of the hair as close to the scalp as possible with a pair of scissors. The sample was then laid on a piece of cardboard, secured with adhesive tape to correctly identify hair roots, and placed in a plastic bag and envelope. Participants then sent their hair samples to the laboratory in a postage-paid envelope.

2.3.3. Hair analyses

Wash and steroid extraction procedures were carried out at the Centre for Studies on Human Stress in Canada (http://humanstress.ca/saliva-lab/general-information/). For each hair sample, two 3 cm segments of hair (25 mg each) were analyzed separately to quantify cortisol concentrations in Segments A and B. Samples were assayed in duplicate using a luminescence immunoassay (detection range: 0.005–4 μg/dl; intra-assay coefficient of variation was 5.24 %; inter-assay coefficient of variation was 8.78 %). Salimetrics specifies that reliable analyses should have intra- and inter-assay coefficients of variation lower than 10 % and 15 %, respectively.

2.4. Statistical analyses

Each segment of HCC (pre-pandemic and during the first lockdown) was described using means and standard deviations. To avoid multicollinearity in the final model, bivariate correlations were run between the two hair segments to verify whether they were strongly correlated (Daoud, 2017). To maximize power (by decreasing the number of independent variables) and to have a predictor of HPA axis activity during the first lockdown while considering baseline (pre-pandemic) cortisol levels, we calculated the relative change in HCC (rHCC) using the following formula: (Segment A – Segment B) / Segment B. Therefore, a negative rHCC would indicate a relative reduction in HPA axis activity in response to the COVID-19 pandemic, whereas a positive value would indicate a relative increase in HPA axis activity. Based on the potential covariates that could affect HCC as identified by Stalder et al. (2017), bivariate correlations were run for continuous variables (hair washing frequency, physical activity, body mass index, weekly caffeine consumption) and t-tests were run for categorical variables (hair washing in the last 24 h, medication use, drug use, tobacco use, hair color, hair product use) to identify any possible confounding variables related to rHCC. To be conservative, all variables with a *p*-value of.100 or lower were considered as possible covariates.

Multilevel linear models were run using the *nlme* package (Pinheiro et al., 2022) within the statistical software R (R Core Team, 2021). All continuous variables were standardized and mean-centered to facilitate interpretability. Given that longitudinal studies violate the assumption of independence of observations, general linear models (e.g., repeated-measures ANOVAs) are inappropriate and could lead to greater type I error rates (Musca et al., 2011). For this reason, multilevel models for longitudinal data (i.e., growth curve analyses) were used using the five timepoints (pre-pandemic, T1, T2, T3, and T4) of alcohol use nested within each participant. These models can statistically account for level 2 variance (inter-participant variance) by allowing the coefficients to vary between the participants (random effect). As recommended by Duplessis-Marcotte et al. (2022), the appropriate random effect structure for the final model was identified by comparing two models: the

random intercept model with a fixed effect of time, as well as the model with both a random intercept and random slope of time. To compare and choose the best model, we used the Akaike Information Criterion (AIC). Data visualization revealed a non-linear effect of time. Therefore, models with linear, quadratic, and cubic effects of time were compared using AIC. Once the best model was identified, the following fixed effects were added to the model: all covariates, the main effects of rHCC and PSS, and their interaction with each other and with time. This allowed us to see if the trend in alcohol use over time was moderated by levels of rHCC and/or PSS. To decompose any significant interactions, the package *emmeans* (Lenth et al., 2022) was used to generate predicted values of the model for values of − 1 *SD* and + 1 *SD* for both rHCC and PSS. Finally, through visual inspection, we verified that the assumptions of homoscedasticity and normal distribution of the residual errors of the final model were respected. If the assumption of homoscedasticity for the model was respected, a residual bootstrap method was retained to calculate the estimates and confidence intervals, whereas a case resampling bootstrap was used if heteroscedasticity was found (van der Leeden et al., 2008).

3. Results

Pre-pandemic levels of HCC (Segment A) had a mean of 27.43 pg/mg (*SD* = 85.45), whereas pandemic levels (Segment B) had a mean of 27.92 pg/mg (*SD* = 82.56). As expected, both segments were highly correlated ($r(77) = 0.99$, $p < .001$), highlighting the necessity of using rHCC to avoid multicollinearity. The rHCC had a mean of 40 % (*SD* = 116). Among the potential covariates for rHCC that were tested, only the dichotomic variable drug user (yes or no) showed a trending correlation ($r(70) = -0.21$, $p = .075$). All analyses were run with and without this covariate. As the results did not change when this covariate was included and for statistical power purposes and parsimony, we only reported the results excluding the covariate in the current paper.

The change in alcohol use at T1 for the full sample is reported in Table 1. Participants who never reported drinking alcohol throughout all timepoints (n = 29) and participants who could not provide enough hair to get the full 6 cm sample (n = 62) were removed from further analyses. As shown in Table 1, the proportion of participants who increased, decreased, or did not change their alcohol use remained unchanged from the original to the final sample (χ^2 (2, N = 197) = 0.45, p = .800). The main reasons that were reported for increasing or decreasing alcohol use at T1 are shown in Table 2.

For longitudinal descriptive analyses, alcohol use was considered as a continuous variable (weekly units of alcoholic beverages consumed). The model with a random intercept and random slope of time (AIC = 1918.62) was a better fit than the model with a random intercept and fixed effect of time (AIC = 1957.48). The intra-class correlation calculated from the unconditional model (random effect of intercept only) revealed that 77 % of the total variance in alcohol use was attributable to level 2 variance (inter-participants). Said differently, the five timepoints of alcohol use within a given participant were highly correlated.

Table 1
Change in alcohol use from T0 to T1.

Drinking status	n (%)		
	Original sample (n = 156)	Original sample without abstainers (n = 118)	Final sample with rHCC (n = 79)
Abstainer	38 (24.4 %)		
Decreased	20 (12.8 %)	20 (16.9 %)	11 (13.9 %)
Same	55 (35.3 %)	55 (46.6 %)	40 (50.6 %)
Increased	43 (27.6 %)	43 (36.4 %)	28 (35.4 %)

Note. After removing abstainers and participants who could not provide 6 cm of hair, the drinking status for the change in alcohol use was not significantly different when comparing the full original sample (n = 156) to the final sample (n = 79) that was kept for further analyses, χ^2 (2, N = 197) = 0.45, p = .800.

Table 2
Reasons for increasing or decreasing alcohol use during the first COVID-19 lockdown.

Reasons for increased alcohol use	%
Relaxation	31.00
More occasions to consume due to lifestyle changes	24.00
Reduce stress/anxiety	20.00
Entertainment/With friends	13.00
Other	5.13
Personal choice	4.27
Alcohol problem (addiction)	1.71
Had extra money to spend	0.85
More choices	0.85
Cost (less expensive, discounts)	0.00
Reasons for decreased alcohol use	
Fewer occasions to consume due to lifestyle changes	34.69
Diminished/lack of interest in drinking alcohol	20.41
Personal choice	12.24
Less money to spend	10.20
Health/medication	8.16
Reduced accessibility to liquor store(s)	8.16
Family responsibilities	4.08
Other	2.04
Pregnancy (or possible pregnancy)	0.00
Trying to stop/limit consumption	0.00

Note. Participants could provide more than one reason for increasing or decreasing alcohol use.

However, some level 1 (within-participant) variance remained across the timepoints. Indeed, the model with a cubic effect of time (AIC = 1909.95) was a more appropriate fit for the longitudinal data trend compared to a linear (AIC = 1918.62) and quadratic model (AIC = 1916.07). Fig. 1 shows that weekly alcohol use increased at T1 and slowly returned to pre-pandemic levels at the remaining timepoints. Tukey's adjusted t-tests for contrasts between T0 (baseline alcohol use) and the other timepoints revealed only a significant difference from T0 to T1 ($t(299) = -0.852$, $p = .031$) but not from T0 to T2 ($t(299) = -0.488$, $p = .605$), T0 to T3 ($t(299) = 0.128$, $p = .998$), or from T0 to T4 ($t(299) = 0.029$, $p = 1.000$). This shows there was an increase in alcohol use from T0 to T1 and that whole sample alcohol use dropped to pre-pandemic levels at T2.

A Pearson correlation revealed no relationship between PSS and rHCC ($r(77) = -0.12$, $p = .274$), suggesting they could be included in the same multilevel model without inducing multicollinearity. Then, based on a comparison of their respective AIC, the model with the three-way interaction was a better fit for the data (AIC = 1681.1) than the model with two-way interactions between rHCC*time and PSS*time

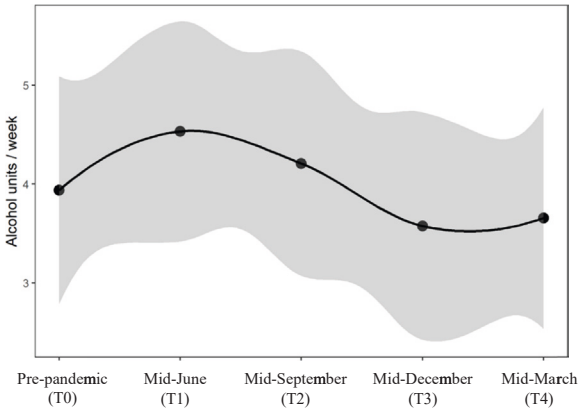

Fig. 1. Whole sample weekly alcohol use during the first year of the pandemic. *Note*. Whole sample weekly alcohol use increased at T1 and decreased to pre-pandemic (T0) levels at T2. Tukey's adjusted t-tests for contrasts between T0 (baseline alcohol use) and the other timepoints revealed only a significant difference from T0 to T1 ($t(299) = -0.852$, $p = .031$). All other timepoint contrasts with regards to T0 were non-significant.

(AIC = 1683.4). Fig. 2 shows the significant three-way interaction between time, rHCC, and PSS, even after controlling for sex assigned at birth, age, and current psychiatric diagnosis. As the homoscedasticity of the model was respected, the residual bootstrap method was retained to calculate the estimates and confidence intervals of the model depicted in Table 3 (van der Leeden et al., 2008). Subsequent pairwise contrasts revealed no differences in alcohol use among individuals lower in PSS (−1 *SD*) across all timepoints, regardless of their rHCC. Among individuals higher in PSS (+1 *SD*), a significant intra-individual difference in alcohol use emerged between the timepoints for individuals high in rHCC. Specifically, individuals with concomitant high levels of rHCC and PSS showed a significant increase in alcohol use from T0 to T1 ($\beta = -3.90$, $t(312.7) = -3.39$, $p = .007$), T0 to T2 ($\beta = -4.19$, $t(287.6) = -3.15$, $p = .016$), and T0 to T4 ($\beta = -4.99$, $t(122.6) = -2.88$, $p = .037$). The difference in alcohol use between T0 and T3 was marginally significant ($\beta = -3.62$, $t(169.8) = -2.50$, $p = .095$). The final model explained 86.7 % of the variance in alcohol use (conditional R^2), with 13.9 % pertaining to fixed effects only (marginal R^2).

Table 3
Bootstrapped coefficients and confidence intervals of the final model.

Fixed effects	Estimates	95 % CI
(Intercept)	8.99***	3.92–14.50
Psychiatric diagnosis	1.66	-0.48 to 4.36
Age	1.24*	0.27–2.13
Sex	-2.93*	-5.84 to − 0.27
rHCC	0.69	-0.80 to 2.29
time	-1.33	-4.70 to 1.81
time(quadratic)	-4.96**	-9.91 to − 2.01
time(cubic)	5.92**	2.96–9.38
PSS	0.61	-0.24 to 1.52
rHCC*time	13.44*	3.04–23.30
rHCC*time(quadratic)	-3.84	-8.89 to 1.14
rHCC*time(cubic)	3.31	-1.87 to 8.18
PSS*time	6.91	-0.52 to 12.00
PSS*time(quadratic)	-1.86	-4.77 to 1.00
PSS*time(cubic)	3.03	0.05–5.95
rHCC*PSS	0.19	-1.17 to 1.46
rHCC*PSS*time	8.90*	1.40–16.90
rHCC*PSS*time(quadratic)	-3.47	-7.40 to 0.87
rHCC*PSS*time(cubic)	3.35	-0.86 to 7.32
Random effects		
SD of (Intercept)	4.02	3.35–4.81
SD of Time (slope)	0.82	0.64–1.04
Observations	381	
Marginal/Conditional R^2	.139/.867	

Note. A residual bootstrap with 200 resamples was used to generate the estimates and confidence intervals of the model. To avoid multicollinearity of the three time variables (linear, quadratic, and cubic), the quadratic and cubic polynomials were computed using the poly() function in R which allowed for the calculation of orthogonal polynomials. The model included a random intercept and a random slope of time. Individual estimates of the random effects for all participants are not presented as our hypotheses did not concern any specific participants. However, the *SD* of the random effects show that there was considerable variance in the intercept of alcohol use and in the slope of alcohol use over time. Said differently, participants differed in their initial alcohol use and in how their alcohol use changed over time. *CI* = Confidence intervals. PSS = Perceived Stress Scale. rHCC = relative change in hair cortisol concentration. *SD* = standard deviation.
*$p<.05$; **$p<.01$; ***$p<.001$.

4. Discussion

The first objective of this study was to describe alcohol use in the year following the first wave of the COVID-19 pandemic in healthy adults. Precisely, we aimed to describe the proportion of individuals who changed their alcohol use and their motives for doing so. We also set out to longitudinally describe whole sample alcohol use for a one-year period following the first COVID-related lockdown implemented in mid-March 2020 in Quebec, Canada. The second objective of this study was to determine how the physiological (via HCC) and subjective stress responses experienced in the first pandemic-related lockdown moderated alcohol use over time.

About half of our sample changed their alcohol use during the first lockdown in Quebec, with 35.4 % of our sample reporting increased alcohol use compared to their pre-pandemic levels. These results replicate the proportion of alcohol use changes found in the literature following the early months of the pandemic (Shimpo et al., 2022). Longitudinal analyses revealed that the whole sample's weekly alcohol intake increased during the first lockdown in June 2020, returned to pre-pandemic levels in September 2020, and plateaued up to one year later. One reason reported by our participants for increasing their alcohol use during the lockdown was an increase in opportunities to drink and lifestyle changes. Indeed, during the first trimester of the pandemic, public health measures, such as physical distancing and lockdown, were related to decreased opportunities for alcohol-free rewarding activities such as sports (Acuff et al., 2021). Knowing that casual alcohol use is initially driven by the positively reinforcing properties of alcohol (e.g., pleasurable and rewarding effects of alcohol (Koob and Schulkin, 2019)), alcohol may have been a rewarding

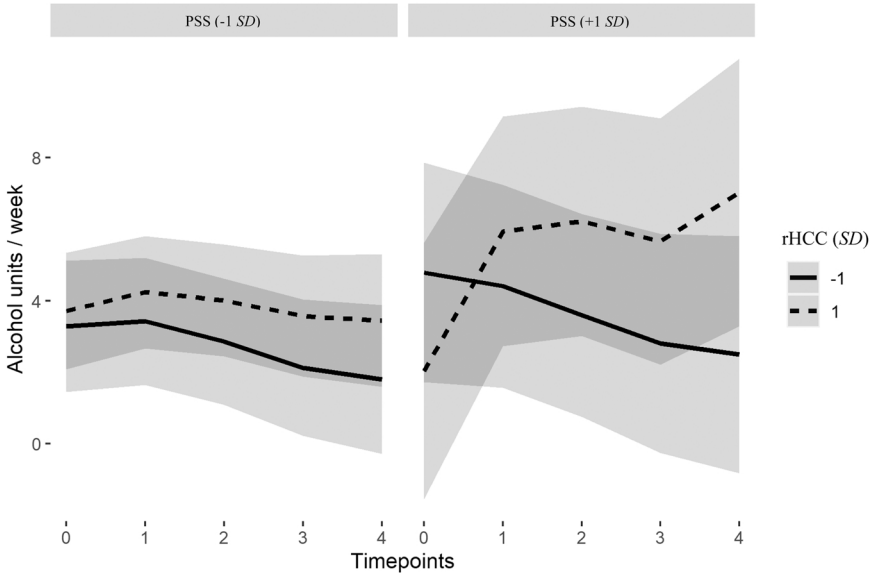

Fig. 2. Three-way interaction between rHCC, PSS, and time to predict alcohol use. *Note*. No intra-individual or inter-individual differences emerged at lower levels of PSS (−1 *SD*). For higher levels of PSS (+1 *SD*), no differences emerged between rHCC levels. However, individuals with higher rHCC during the first COVID-19 lockdown increased their alcohol use compared to pre-pandemic (T0) levels. Moreover, this increase was maintained at T4. PSS = Perceived Stress Scale. rHCC = relative change in hair cortisol concentration. *SD* = standard deviation.

alternative in the short-term (i.e., first trimester of the pandemic (Acuff et al., 2019)). Once the confinement measures were lessened, these increased opportunities to drink may have become less frequent (e.g., reopening of businesses and academic activities), whereas alcohol-free rewarding activities more so, which could explain the decrease in alcohol use observed in September 2020.

To our knowledge, no other studies have reported longitudinal alcohol use beyond the first pandemic-related lockdown (first trimester). However, our results coincide with longitudinal analyses of mental health conducted during the many months of the pandemic and revealed a certain level of resiliency; the levels of anxiety and depression mostly came back to pre-pandemic levels (Manchia et al., 2022). Accordingly, one of the main reasons reported by our participants for increasing alcohol use in the first trimester of the pandemic was to relax and/or to reduce stress. Subjective stress has been suggested to act as a signal that alerts the individual to reach or re-establish emotional homeostasis, such as through alcohol use (Greeley and Oei, 1999). Moreover, individuals reporting greater negative affect show greater stress-response dampening effects after consuming alcohol (Hefner and Curtin, 2012). This suggests that for individuals reporting greater subjective stress, alcohol may have a greater effect on reducing stress symptoms and thus, are at a greater risk of adopting alcohol consumption as a coping strategy. In light of these studies and our findings, one could postulate that subjective stress is a *necessary* factor to increase alcohol use (i.e., increase motivation to drink alcohol to alleviate emotional distress). Accordingly, the association between stress self-reports and alcohol use during the early pandemic is a prominent finding (Schmidt et al., 2021). Yet, concomitantly assessing the physiological stress response is necessary to better understand alcohol use, as it is the cornerstone of recent models of alcohol use and misuse (Blaine and Sinha, 2017; Koob and Schulkin, 2019).

Consistently, we found that the interaction between subjective and physiological stress responses predicted alcohol use throughout the first year of the pandemic. Our results revealed that alcohol use increased *only* in individuals experiencing both high subjective stress and a more pronounced relative increase in HPA axis activity during the first lockdown (i.e., the first trimester of the pandemic). This was depicted by increased HCC between March and June 2020 compared to pre-pandemic HCC (between December 2019 and March 2020). These results align with and can be explained by the influential allostasis model of the development of addiction proposed by Koob et al. (2019). This model states that the transition from casual alcohol use to long-term increases in alcohol use is the result of a gradual motivational shift from positive to negative reinforcement (e.g., alleviating negative affect). Importantly, this transition is believed to be mediated by allostatic changes in HPA axis activity. It has been shown that repeated alcohol use induces allostatic adaptations in HPA axis activity, resulting in higher basal levels of glucocorticoids (i.e., a class of steroid hormones including cortisol in humans), as well as a blunted glucocorticoid response to alcohol intake in rodents (Koob and Schulkin, 2019) and humans (Blaine and Sinha, 2017). Consistently, our results suggest that compared to pre-pandemic cortisol levels, elevated cortisol during the first trimester of the pandemic (higher rHCC) was necessary to predict increased alcohol use a year later. However, this was *only* true for individuals who also experienced greater subjective stress. Our analyses showed that the interaction between subjective stress and rHCC more accurately predicted alcohol use during the pandemic than when subjective stress and rHCC were considered independently. Therefore, our results support Koob's animal model of alcohol use but highlight the importance of investigating subjective stress in parallel when studying humans. In brief, we postulate that this vicious cycle of alcohol use, HPA axis activity and allostatic adaptation, alongside increased subjective stress, could have led to increased alcohol use levels a year into the pandemic.

It is important to emphasize that our sample was comprised of healthy individuals who were previously selected due to their limited possession of risk factors for various disorders (e.g., addiction). Although alcohol intake levels were not alarming one year into the pandemic, these results warrant further investigation. Specifically, the observed increased alcohol use could lead to the development of compulsive drinking patterns associated with alcohol addiction (Koob and Schulkin, 2019). With regards to the first trimester of the pandemic, it is impossible to disentangle whether the increase in HPA axis activity happened before or after alcohol use increased. Future studies should longitudinally assess reward sensitivity (to alcohol), basal and reactive cortisol levels, and alcohol use in healthy individuals to verify whether HPA axis allostatic adaptations precede or succeed increases in alcohol use. In other words, increased basal HPA axis activity (possibly due to a stressful event) may render an individual more vulnerable to the negatively reinforcing value of alcohol.

Our study comes with certain limitations. First, our alcohol use measure was only able to quantify weekly consumption amounts. Other measures might be more indicative of hazardous drinking behaviors, such as binge drinking (Jones et al., 2018; Maurage et al., 2020; Sacks et al., 2015). Second, due to the 6 cm hair sample length requirement, our sample was comprised of more women than men. The latter prevented us from exploring sex differences. This requirement also restricted our analyses to a smaller sample size of 79 participants. However, the use of a longitudinal design allowed us to increase our power by collecting a total of 381 data points over the five timepoints. Third, it has been noted that more distal hair segments suffer from greater degradation and in turn, could have contributed to artificially decreasing HCC levels of the pre-pandemic hair segment compared to the hair segment collected during the pandemic (Stalder et al., 2017). However, previous studies suggest that HCC is stable for the 6 cm closest to the scalp (i.e., the length utilized in the current study; Dettenborn et al., 2010; Rajcani et al., 2021). Finally, our sample consisted of individuals who previously participated in studies from our research laboratory. As our team measures neuroendocrine biomarkers, potential participants are extensively screened and excluded if they have psychiatric disorders, consume drugs, smoke more than seven cigarettes per day, and display hazardous drinking behaviors. Therefore, drinking behaviors in our sample may have been unrepresentative of that of the general population. For instance, our sample had a greater percentage of abstainers (24.4 %) than the general population in Quebec (17 %; www.educalcool.qc.ca/). However, the obtained result in our sample showing safer health and drinking behaviors warrants replication in a more representative sample.

4.1. Recommendations and conclusions

As reported by some of our participants, their alcohol use increased due to additional drinking opportunities that arose due to the context of the pandemic. For example, liquor stores were declared to be an essential service in Quebec during the lockdown and thus, remained open. Moreover, the government alleviated restrictions on alcohol sales to help restaurant owners. Indeed, although not previously allowed in Quebec, restaurant owners could sell alcohol with delivery food orders during the pandemic. Therefore, public health strategies may be warranted to limit the ease of access to alcohol in future global crisis events. To nudge the population towards less risky alcohol use behaviors, public health authorities could employ behavioral economic techniques (Acuff et al., 2021; Münscher et al., 2016). For example, these techniques could act to facilitate access to and encourage involvement in substance-free rewarding activities (Acuff et al., 2019). Indeed, it has been shown that simply instructing individuals to get more involved in sports or crafts resulted in decreased alcohol use up to one month later (Correia et al., 2005). However, it is important to remember that alcohol serves as an emotional regulator for some individuals and is socially trivialized. Therefore, it is recommended that sensitization campaigns be developed to inform the population about the risks associated with alcohol use (particularly in stressed out individuals) and alternative solutions that

can be used to cope with stress and other negative emotions in times of crisis.

From a theoretical standpoint, this study highlights the importance of concomitantly investigating the predictive value of subjective and physiological stress response systems when assessing changes in alcohol consumption in response to environmental challenges. This study also suggests that assessing alcohol use changes could help identify individuals that are experiencing greater subjective and physiological distress. As suggested by the late Bruce McEwen (McEwen, 2008), health behavior changes may reflect greater chronic stress, as well as wear and tear of the body's stress response systems. Therefore, in clinical practice, assessing health behavior changes (notably, alcohol use) may be a more sensible proxy for emotional long-term distress than simply asking "are you stressed?".

CRediT authorship contribution statement

Félix Duplessis-Marcotte: Conceptualization, Formal analysis, Investigation, Writing – original draft, Visualization, Project administration. **Raphaël Lapointe:** Writing – original draft, Visualization. **Sonia J. Lupien:** Writing – review & editing. **Marie-France Marin:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Funding acquisition, Project administration.

Declarations of interest

None.

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