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Affect Relative to Day-Level Drinking Initiation: Analyzing Ecological Momentary Assessment Data with Multilevel Spline Modeling

Michael A. Russell,
The Pennsylvania State University

Ashley N. Linden-Carmichael,
The Pennsylvania State University

Stephanie T. Lanza,
The Pennsylvania State University

Emily V. Fair,
The Pennsylvania State University

Kenneth J. Sher,
University of Missouri, Columbia

Thomas M. Piasecki
University of Missouri, Columbia

Abstract

Affect regulation models state that affect both motivates and reinforces alcohol use. We aimed to examine whether affect levels and rates of change differed across drinking versus non-drinking days in a manner consistent with affect regulation models. 404 regularly drinking adults, aged 18–70 years, completed ecological momentary assessments (EMA) over three weeks. Participants provided positive affect (PA; enthusiastic, excited, happy) and negative affect (NA; distressed, sad) reports during all prompts; alcohol consumption reports were also provided. Multilevel spline models revealed that on drinking days, PA was higher and NA was lower both before and after drinking compared to matched times on non-drinking days. PA and NA were also higher and lower, respectively, both before and after drinking, when heavy drinking days were compared to moderate drinking days. Examination of affect rates of change revealed that (a) accelerating increases in PA and accelerating decreases in NA preceded drinking initiation, (b) PA increases and NA decreases were seen up to two hours after drinking initiation, and (c) pre- and post-drinking PA increases were larger on heavy versus moderate drinking days, whereas only post-drinking NA decreases were larger on heavy drinking days. Results supported affect regulation

Please address correspondence to Michael A. Russell, Department of Biobehavioral Health, The Pennsylvania State University, 219 Biobehavioral Health Building, University Park, PA, 16802. mar60@psu.edu.
Michael A. Russell, Department of Biobehavioral Health, The Pennsylvania State University; Ashley N. Linden-Carmichael, Department of Biobehavioral Health and Prevention Research Center; The Pennsylvania State University; Stephanie T. Lanza, Department of Biobehavioral Health and Prevention Research Center; The Pennsylvania State University; Emily V. Fair, Department of Biobehavioral Health, The Pennsylvania State University; Kenneth J. Sher, Department of Psychological Sciences, University of Missouri; Thomas M. Piasecki, Department of Psychological Sciences, University of Missouri.

models while adding nuance, showing accelerating changes in pre-drinking affect on drinking days, and pre- and post-drinking differences in affect levels and rates of change across days of varying drinking intensity. Beyond theory, our results suggest that accelerating changes in affect may provide a clue to future commencement of heavy drinking, which may aid momentary intervention development.

Keywords

Affect regulation models; alcohol; ecological momentary assessment; multilevel spline modeling

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Affect plays a central role in theoretical models of the antecedents and sequelae of alcohol misuse (Sher & Grekin, 2007; Wray, Simons, Dvorak, & Gaher, 2012). These *affect regulation models* generally include two related propositions: (1) that both positive (PA) and negative affect (NA) can motivate alcohol consumption and (2) that alcohol consumption is partly reinforced through pleasurable changes in affect, including decreases in NA and increases in PA (Dvorak et al., 2018; Kuntsche & Bruno, 2015; Sher & Grekin, 2007). As such, affective regulation models place emotional experiences on both “sides” of a drinking event, both before and after drinking has begun.

Research supports both sides of affect regulation models (Dvorak et al., 2018; Treloar, Piasecki, McCarthy, Sher, & Heath, 2015). Evidence is more consistent for PA than for NA, and more work has been done focusing on affect prior to drinking than on affect following drinking (Dvorak et al., 2018; Sher & Grekin, 2007). Evidence from daily process studies, in which drinkers are queried about their affect and drinking behavior via daily diaries or ecological momentary assessments (EMA) in everyday life, shows that daytime PA and NA are consistently associated with nighttime drinking behavior (Dvorak, Pearson, & Day, 2014; Dvorak & Simons, 2014; Mohr et al., 2005; Simons, Dvorak, Batien, & Wray, 2010; Simons, Wills, & Neal, 2014). Robust positive associations are seen between daytime PA and nighttime drinking, with greater daytime PA being associated with more nighttime drinking (Dvorak et al., 2014; Dvorak, Pearson, Sargent, Stevenson, & Mfon, 2016; Dvorak & Simons, 2014; Simons et al., 2010; Simons et al., 2014; Swendsen et al., 2000). The direction of the relationship between pre-drinking NA and alcohol outcomes, however, tends to vary across studies, with some studies showing positive relationships (greater daytime or early-day NA associated with greater nighttime or later-day alcohol consumption; Dvorak et al., 2014; Dvorak et al., 2016; Simons et al., 2014; Todd, Armeli, & Tennen, 2009) and some studies showing negative relationships (lower daytime or early-day NA associated with greater nighttime or later-day alcohol consumption; Dvorak et al., 2018; Simons et al., 2010; Treloar et al., 2015). Experimental studies also provide evidence, showing that positive and negative affect induction paradigms can elicit changes in laboratory alcohol consumption and alcohol expectancies (Dinc & Cooper, 2015; Grant & Stewart, 2007), although these effects are not universally detected (Wardell, Read, Curtin, & Merrill, 2012).

Daily process and experimental studies examining affect *after* alcohol consumption are fewer, but generally support the notion that PA increases, and NA decreases, following alcohol consumption (Conrod, Peterson, & Pihl, 2001; Crooke et al., 2013; Dvorak et al., 2018; Wilkie & Stewart, 2005), although not all studies show this (Crooke et al., 2013; Treloar et al., 2015; Wilkie & Stewart, 2005), and some evidence suggests that changes in alcohol-related expectancies may be driving the effect (Sitharthan, Sitharthan, & Hough, 2009). Additionally, the dynamic nature of affective experience has led investigators to more directly investigate affective change or variability, in addition to affective level, as both a predictor and an outcome of alcohol misuse in everyday life; studies have consistently shown that greater affective variability (PA or NA), perhaps indicative of emotional dysregulation, is associated with more alcohol misuse (Dvorak et al., 2018; Gottfredson & Hussong, 2013; Kuntsche & Bruno, 2015; Simons et al., 2014).

This previous work has provided exciting and important findings supporting the hypothesized associations between affect and drinking, both before and after drinking initiation. A deeper understanding of affect as an antecedent as well as a consequence of alcohol consumption is needed, however, not only for theoretical verification, but also for intervention planning. A focus on affective change as it unfolds in everyday life provides an important basis for developing ecological momentary intervention (EMI) strategies focused on "just-in-time" messaging, where intervention content is delivered – typically via mobile devices – during moments of need, for at-risk individuals (Heron & Smyth, 2010). Pre-drinking affect may be especially important as it may assist in forecasting a heavy drinking event and thus be useful in the design and targeting of just-in-time interventions, but more information is needed. For example, previous daily process studies have generally taken the average level or the average amount of variability (via the mean of squared successive differences [MSSD]) in daytime affect and used these to predict nighttime alcohol consumption (Dvorak et al., 2016; Dvorak et al., 2018). While such an approach is useful for determining if daytime affective levels and variability, respectively, predict later drinking behavior, it cannot inform us about the timing of affective change relative to when drinking occurs. Affect is a highly dynamic construct, with the potential for both rapid reversible change from moment to moment as well as more structured change including diurnal cycles and day-of-week trends (Smyth, Neubauer, & Russell, 2018). To test whether affect on drinking days is higher, lower, or more variable than affect during the same hours on non-drinking days forces the analyst to crudely smooth over more temporally nuanced affect levels and rates of change, obscuring the temporal process and removing information about when, how, and in what direction affect is changing prior to and after drinking is initiated. This lost information could not only assist in the verification and expansion of affect regulation models, but could also be useful in the planning of real-time intervention, as the interventionist may learn to look for shifts in affect that may foretell a heavy drinking event and time intervention messages accordingly.

In the current paper, we report on an EMA study of naturalistic alcohol use episodes among 404 frequently drinking adults. Unique features of this paper include (a) intensive sampling of affect and alcohol consumption during naturalistic drinking episodes and (b) the use of multilevel spline modeling, an approach to elucidate non-linear, time-varying levels, rates of change, and associations between covariates while accounting for nesting that occurs at multiple levels (here moments within days, and days within people). Using this combination of intensive episode-specific EMA and multilevel spline models, we set out to test the dual propositions of affect regulation models (pre-drinking affect as a motivator of drinking, post-drinking affect as a reinforcement mechanism; Dvorak et al., 2018; Sher & Grekin, 2007) in a novel way by examining both pre- and post-drinking affect levels and changes as they unfolded over time in people's naturalistic settings, across drinking and non-drinking days. Specifically, we asked the following research questions:

1. *When, for how long, and by how much do PA and NA differ across drinking and non-drinking days, relative to drinking initiation?* We compared affect levels on drinking days, before and after drinking begins, with affect levels on non-drinking days during matched times for that individual. With these tests, we sought to determine whether times of high and low affect are specific to drinking versus non-drinking days, and not simply due to temporal rhythms in affect.

2. *What is the magnitude and timing of affective change relative to drinking initiation, and how does this differ from non-drinking days?* Using derivatives implied by multilevel spline affect curves, we examined when, relative to drinking initiation, affect was significantly changing, how much it was changing, and what its overall pattern of change across the day appeared to be. With these tests, we sought to uncover whether drinking versus non-drinking days in our sample could be differentiated in terms of their affective rates of change, both before and after a person's typical drinking initiation time.

3. *Can affect levels and rates of change differentiate heavy from moderate drinking days?* Looking only at drinking days, we then compared affect curves by drinking intensity, examining whether affect levels and rates of change statistically differ on heavy (4+/5+ drinks for women/men) versus moderate drinking days (1–3/1–4 drinks for women/men). These tests were conducted to determine whether affect level and change, prior to and after drinking initiation, could distinguish between heavy and moderate drinking days and thereby offer information that may assist in theoretical development and detection of heavy drinking episodes in naturalistic settings.

Method

Participants

The current study reports on results from 404 current drinkers who reported alcohol consumption on four or more occasions in the past 30 days. Because a major focus of the overarching data collection effort was to examine the effects of alcohol and tobacco co-use in everyday life, an oversampling of current smokers (n = 259; 64.1% of the sample) was included by design; the remaining individuals were current drinkers who did not smoke (n = 145; 35.9% of the sample). Participants were recruited through advertisements posted on public kiosks, published in a widely distributed circular, and sent by mass e-mail to employees and students at the University of Missouri. Participants could earn up to $150 for full participation. Of the 404 participants, 50.3% were women; 84.7% were non-Hispanic white, 0.7% American-Indian/Alaskan Native, 5.2% Asian, 3.2% black, 0.3% Native Hawaiian/Pacific Islander, 3.5% another race, and 2.5% Hispanic or Latinx ethnicity. Ages ranged from 18 to 70 years (M age = 23.4, SD = 7.4).

EMA Device and Procedure

Full details of the EMA protocol are described elsewhere (Piasecki et al., 2011). Briefly, EMA measurement was implemented with palmtop computers (Palm m500, Palm, Inc., Sunnyvale, CA) programmed with customized software designed by invivodata, inc. (Pittsburgh, PA). The overall assessment scheme encompassed five types of entries: (a) time-based random prompts, (b) user-initiated cigarette reports in which participants logged instances of cigarette use, (c) user-initiated drinking reports, in which participants logged completion of the first drink in a drinking episode, (d) a series of automated, prompted drinking follow-ups collected in the wake of the first drink log, and (e) morning reports made each day after waking.

Assessment schedule and sequence.—During non-drinking periods, participants made morning reports each day upon waking, electronic diaries delivered random prompts (up to five per day, spaced approximately 2.75 hours apart on average), and participants completed cigarette reports (if they smoked). When any drinking was reported in the random or user-initiated drinking or cigarette reports, the device initiated a drinking follow-up sequence, which delivered audible prompts at 30-, 90-, and 150-minute latencies after the first drink. The sequence of follow-ups was extended by 1 hour each time a new drink was reported in a follow-up. The sequence continued until all scheduled follow-ups were completed or until the participant indicated he or she was retiring for the evening. Importantly, initiation of the drinking follow-up sequence pre-empted all other reporting modes, meaning that cigarette and drinking reports could not be initiated while the drinking follow-up sequence was running, and random prompts were not sampled during periods of ongoing alcohol use. If all scheduled drinking follow-up prompts were completed but the participant did *not* retire for the evening, drinking was assumed to have terminated and the assessment schedule reverted to the random prompts and user-initiated reports delivered during non-drinking periods. In all, this assessment procedure captured 61,736 observations nested within 8,542 diary days nested within 404 people. All procedures were approved by the institutional review board at University of Missouri.

Diary days and time relative to drinking initiation.—The time metric that was central to our research questions was time relative to drinking initiation within a person's experienced day. The hours a person experiences as their "day" (and the hours in which drinking behaviors occur) do not always line up with the midnight-to-midnight hours of a calendar day, and the same clock times can have different meanings across days and people, depending on schedules. Thus, instead of midnight, we considered the time of the morning report to be the start of a new day and the end of the previous day, and counted within-day time using the number of hours since the morning report, as this measure aligns with how a person would experience time within their day. This was done for both drinking and non-drinking days, so that comparisons across day types would be on the basis of experiential time and not on the basis of clock time. We use the term "diary days" hereafter to represent this demarcation of experiential days using the morning report times. The morning report tended to occur at approximately 9:25 AM (SD = 2 hours, 21 minutes); days with no morning report (14% of days) used the person's mean morning report time to mark the start of the day. Then, using experiential time (hours since morning report) as the underlying time dimension, time within each drinking day was centered on the time the first drink was recorded for that diary day. The mean first drink time was approximately 10.6 hours since the morning report (SD = 3.6). The same procedure was used on non-drinking days, with time relative to drinking being generated through centering on the person's average drinking time, in morning report hours. Using this procedure on both drinking and non-drinking days gives the "0" point of time relative to drinking initiation the same meaning on both types of days: it is the person's average time of drinking initiation relative to when they woke up, with negative hours being hours prior to a person's typical drinking initiation time and positive hours being hours after a person's typical drinking initiation time.

Measures

Affect.—Positive affect (PA) and negative affect (NA) were assessed at each of the 5 report types (morning, random, cigarette report, drinking report, and drinking follow-up) using the positive and negative affect scale (PANAS; Watson, Clark, & Tellegen, 1988) adapted for use in EMA. Questions referred to the person's experience of specific affects over the past 15 minutes; participants were asked to rate each affect item on a 5-point scale from *not at all (scored 0)* to *extremely (scored 4)*. PA items included *happy*, *excited*, and *enthusiastic*; NA items included *sad* and *distressed*. To assess scale reliability, the *omega* statistic (ϖ), which represents the proportion of true score variance to total variance across all items (Shrout & Lane, 2012), was calculated at the within-day, between-day, and between-person levels of analysis for each affect composite in a three-level confirmatory factor analytic (CFA) structural equation model. Given that only two items were available for NA (distressed and sad), item residual variances were constrained to be equal across items in order to allow model identification; this was done at all three levels of analysis. For PA, omega reliability was acceptable at all three levels (within-day ϖ = 0.71, between-day ϖ = 0.95, between-person ϖ = 0.97). For NA, omega reliability wasadequate at the within-day level (within-day ϖ = 0.60), and was substantially higher at between-day (ϖ = 0.87) and between-person (ϖ = 0.93) levels. Intraclass correlations (ICC) at the person, day, and within-day levels were calculated for PA and NA using a three-level random effects analysis of variance specification in PROC MIXED. For PA, the person-level ICC was 0.38, the day-level ICC was 0.17, and the within-day level ICC was 0.45; these values indicate that 38%, 17%, and 45% of the variance in PA was present at the person-, day-, and within-day level, respectively. For NA, person-, day-, and within-day ICC values were comparable (0.39, 0.18, and 0.43, respectively).

Alcohol consumption.—Participants could indicate their first alcoholic drink of the day in two ways: (1) by responding *Yes* (versus *No*) to a question asking whether they had consumed alcohol since the last recording (delivered in random prompts or user-initiated cigarette reports) or (2) by logging an alcoholic drink in a user-initiated drinking report. Following the report of either of these, the drinking follow-up report sequence was then initiated. During drinking follow-ups, participants reported on the number of drinks they had consumed since the last recording, with response options ranging from 0 to 6 (or more, coded at 6). As such, random prompts, cigarette reports, and drinking reports where drinking was indicated were coded as the start of a drinking episode, and drinking follow-up reports that immediately followed one of these were coded as belonging to that drinking episode.

Diary days with one or more drinking episodes were classified as drinking days (*n* = 2,668 days; 31.2% of diary days); days without drinking episodes were classified as non-drinking days (*n* = 5,874 days; 68.8% of diary days). The grand mean number of drinks reported across all days (including non-drinking days) was 1.73 (*SD* = 3.72, *Median* = 0, *Mode* = 0); the grand mean number of drinks across all drinking days was 5.52 (*SD* = 4.84, *Median* = 4.00, *Mode* = 1.00). Drinking days were then further characterized according to the total number of drinks consumed. Days in which a person exceeded previously published guidelines for low-risk drinking by the NIAAA (National Institute on Alcohol Abuse and Alcoholism (NIAAA), 2016) (more than three drinks for women and more than four drinks for men) were termed *heavy drinking days*. Heavy drinking days were 16.0% of all diary days and were 51.3% of drinking days; an average of 8.8 drinks were consumed on heavy drinking days (*SD* = 4.8, *Median* = 7.0, *Mode* = 5.0). Drinking days that did not meet the heavy drinking threshold were termed *moderate drinking days*. Moderate drinking days were 15.2% of all diary days and 48.7% of drinking days; an average of 2.1 drinks were consumed on moderate drinking days (*SD* = 1.0, *Median* = 2.0, *Mode* = 1.0).[1]

Drinking intentions were assessed daily during each morning report. Participants responded to the question "What is the likelihood that you will drink tonight?" on a 1 to 5 scale (unlikely to very likely). Participants reported low intentions to drink on the majority of days ("1" or "2" was endorsed on 57.4% of days, *M* = 2.4, *SD* = 1.4), and participants were modestly accurate as this intentions measure correlated significantly (but modestly) with whether or not drinking occurred that day ($r = 0.44$, $p < 0.001$). Drinking intentions were added to our models as a covariate to adjust for the possibility that affective changes prior to drinking could be explained, at least partially, by a person's anticipation of the drinking event.

Statistical Analyses

Multilevel spline models used in the current study combined (a) cubic regression splines used in generalized additive modeling (Hastie & Tibshirani, 1990) and time-varying effect modeling (Tan, Shiyko, Li, Li, & Dierker, 2012) with (b) mixed model estimation of covariance parameters. This allowed the model to both flexibly capture non-parametric coefficient functions while simultaneously accounting for multiple levels of nesting (moments within days, days within people), a feature not traditionally available in generalized additive modeling or time-varying effect modeling packages. Models were estimated in SAS PROC MIXED. Separate spline basis sets, ranging in complexity from 0 to 6 knots, were created for use in model selection. Knots were placed on evenly spaced quantiles of the time axis (Li et al., 2017). Model selection for PA and NA occurred separately. Models were compared using deviance (−2*log likelihood), Akaike's information

[1]It is possible that differences in sampling intensity across drinking day types may at least partially explain the differences we see in affect levels and change. Using regression with clustered standard-errors (by ID), we found that the number of affect reports provided on each person-day was higher (a) if it was a drinking versus non-drinking day (*M* drinking = 8.47 reports, *M* non-drinking = 4.93 reports, $b = 3.54$, $SE(b) = 0.09$, $p < .001$) or (b) a heavy versus moderate drinking day (*M* heavy = 9.01 reports, *M* moderate = 7.91, $b = 1.10$, $SE(b) = 0.14$, $p < .001$). However, when we adjust our multilevel spline models for the number of affect reports provided on each person-day, we find no evidence that the results concerning drinking vs non-drinking or heavy vs moderate drinking day affect curves are meaningfully altered. We therefore conclude that although a difference in sampling intensity exists across drinking day types, it did not appear to meaningfully contribute to differences in the affective trends we observed.

criterion (AIC), and Bayes' information criterion (BIC). All models used cluster-robust standard errors implemented via the Huber-White "sandwich" formula to facilitate statistical inferences (Liang & Zeger, 1986).

The unconditional model submitted to model selection procedures is displayed in Equation 1.

$$Affect_{idt} = \beta_0(T) + \alpha_0(\bar{t}_i) + \alpha_1(\bar{t}_{id}) + \upsilon_{00i} + u_{0id} + \varepsilon_{idt} \quad (1)$$

Equation 1 shows that affect for person i on day d at time $t\,(Aff_{idt})$ is a function of both fixed and random parameters. The fixed portion of the model contains the time-varying level of affect defined by cubic spline bases and their coefficients [$\beta_0(T)$] as well as adjustments for differences in the patterning of assessment times at the person- and day levels [$\alpha_0(\bar{t}_i)$ and $\alpha_1(\bar{t}_{id})$, respectively]; adjusting for these person- and day-level differences removes person- and day-level variability in patterning of time and ensures the affect trajectory represents a within-person, within-day process (Bolger & Laurenceau, 2013). The random portion of the model contains two random intercepts: one at the person level (v_{00i}), which accounts for person-level clustering, and one at the day level (u_{0id}), which accounts for day-level clustering. In addition to adjustment for clustering, random intercepts allow each person and day to have a different level of positive or negative affect. The model also includes a within-person, within-day residual (ε_{idt}). Once the appropriate number of knots for PA and NA models was selected, we used this best-fitting spline specification to address each of our research questions. All subsequent models adjusted for biological sex (male vs female); smoking status (smoker vs non-smoker); sociability of the day, defined as the percentage of prompts that the individual reported being with others; weekend (Friday, Saturday, Sunday) versus weekday (Monday through Thursday); and drinking intentions. All covariates were centered at their grand means in order to preserve the interpretation of the estimated affect curve as that for an average individual on an average day.

Question 1: When, for how long, and by how much do PA and NA differ across drinking and non-drinking days, relative to drinking initiation?

We used equation 1 below to estimate the time-varying difference in affect across drinking and non-drinking days.

$$Affect_{idt} = \beta_0(T) + \beta_1(T)(Drinking_{id}) + \alpha_0(\bar{t}_i) + \alpha_1(\bar{t}_{id}) + \alpha_2(\overline{Drinking_i}) + \upsilon_{00i} + u_{0id} + \varepsilon_{idt} \quad (2)$$

Equation 2 adds the $\beta_1(T)$ coefficient function (defined by interactions between the drinking variable and cubic spline bases) capturing the time-varying difference in affect across drinking versus non-drinking days. Equation 2 also contains a time-invariant coefficient (α_2) for the increase in a person's average affect associated with increases in a person's overall drinking frequency ($\overline{Drinking_i}$), expressed as the proportion of days that were drinking days for person i. $\overline{Drinking_i}$ was centered on its grand mean, and was adjusted in order to remove between-person variance in the drinking day variable, allowing the $\beta_1(T)$ association to represent a within-person, between-day association at each time point (Bolger & Laurenceau, 2013). Estimated values, standard errors, and 95% confidence intervals (CI) for drinking day curves [$\beta_0(T) + \beta_1(T)$], non-drinking day curves [$\beta_0(T)$], and their time-varying difference [$\beta_1(T)$] were generated at 20 values of t via linear combinations of model parameters using ESTIMATE statements in SAS PROC MIXED. This allowed us to determine both the (a) time-varying levels of affect (and their precision) along with (b) the size and statistical significance of the drinking versus non-drinking day difference in affect at each time point. Interested readers may refer to the technical supplement for additional mathematical and analytic details.

Question 2: What is the magnitude and timing of affective change relative to drinking initiation, and how does this differ from non-drinking days?

Taking the first derivatives of affect curves on drinking and non-drinking days reveals the *instantaneous rates of change* in affect across time. These reveal how fast and in what direction affect is changing at each moment (increasing if positive, decreasing if negative). Instantaneous rates of change were estimated from the model specified in equation 2 by taking the first derivatives of drinking day affect curves [$\beta_0(T) + \beta_1(T)]'$, non-drinking day affect curves [$\beta_0(T)]'$, and the time-varying difference in affect curves [$\beta_1(T)]'$, which reveals the time-varying difference in the instantaneous rate of affective change. Derivatives were scaled such that they represented the rate of change in affect per hour at each time point. ESTIMATE statements were used to generate these scaled derivative functions and their 95% CIs from linear combinations of model parameters at 20 values of time relative to drinking; rates of change and differences in rates of change across drinking and non-drinking days were declared significant at all time points when their 95% CI did not include 0. Interested readers may refer to the technical supplement for additional mathematical and analytic details.

Question 3: Can affect levels and rates of change differentiate heavy from moderate drinking days?

Procedures discussed previously for questions 1 and 2 were then applied to drinking days only to test the time-varying differences in affect levels and rates of change across heavy versus moderate drinking days. Moderate drinking days were specified as the reference days.

Results

Model selection

PA and NA scales were only modestly correlated at the within-person, within-day level (r = −0.28), supporting separate modeling of PA and NA processes. Table 1 shows the model selection criteria for unconditional models of PA and NA by time relative to first drink time. For both PA and NA, model fit criteria suggested that a 3-knot specification offered the best fit to the data. Models for PA showed decreases in BIC with each additional knot until an *increase* was seen comparing the 4-knot with the 3-knot model. Deviance and AIC showed similar patterns. Models for NA were similar; decreases in BIC were seen with each additional knot until an increase was seen comparing the 4-knot model to the 3-knot (deviance and AIC again showed similar patterns). Thus, the 3-knot specification was retained for all PA and NA models.

Question 1: When, for how long, and by how much do PA and NA differ across drinking and non-drinking days, relative to drinking initiation?

Positive affect.—Panel A of Figure 1 shows the model-estimated PA curves for drinking (black) and non-drinking days (gray). The solid lines represent the model-estimated PA curves; the dotted lines represent the 95% confidence limits for each curve. The test of the time-varying difference in PA across drinking versus non-drinking days (the $\beta_1(T)$ function) revealed that PA was significantly higher on a person's drinking days than it was at similar times on non-drinking days; times of significant difference are denoted via the dots and barbells above the time axis in Figure 1, Panel A. Starting at approximately 5 hours prior to drinking (*hours* = −5), the difference appeared to become larger, reaching its peak 2 hours after the person's typical first drink time (*hours* = 2). The difference then became smaller thereafter, but remained more pronounced than what was observed prior to drinking.

Negative affect.—Panel B of Figure 1 shows the model-estimated NA curves for drinking and non-drinking days (black and gray, respectively), with solid lines representing model-estimated NA curves and dotted lines representing 95% confidence limits. The test of the time-varying difference in NA across drinking versus non-drinking days (the $\beta_1(T)$ function in Equation 3) revealed that NA levels were significantly lower on drinking versus non-drinking days (areas of significant difference marked with dots and barbells). The difference in NA across drinking and non-drinking days was particularly pronounced starting 3 hours prior to drinking initiation (*hours* = −3), reaching its peak two hours after drinking was initiated (*hours* = 2). The difference then appeared to show a slow and steady decrease until becoming non-significant 6 hours after drinking started (*hours* = 6).

Question 2: What is the magnitude and timing of affective change relative to drinking initiation, and how does this differ from non-drinking days?

Positive affect.—Figure 2 shows derivative curves for PA on drinking days (Panel A, in black) and non-drinking days (Panel B, in gray), which provide a different way of looking at affect curves presented in Figure 1 and allow examination of the magnitude and statistical significance of momentary affective change across time. Panel A illustrates time-varying PA change on drinking days, both prior to and after drinking began, showing that PA rates of change on drinking days were significantly different than they were on non-drinking days at many points throughout the day (see the dots and barbells marking these times in Panel A). Panel A of Figure 2 shows positive values for all pre-drinking PA rates of change, suggesting that PA was significantly and continuously increasing throughout the pre-drinking period on drinking days. PA rates showed acceleration 5 hours prior to drinking initiation (*hours* = −5), and continued to accelerate until reaching their peak 2 hours prior to drinking (*hours* = −2). This interval (from −5 to −2 hours) was the only pre-drinking time period in which accelerating PA was observed. PA continued to increase following this point, albeit more slowly, until becoming non-significant at 2 hours after drinking initiation (*hour* = 2), after which PA began to significantly *decrease*, and continued decreasing significantly until 7 hours after drinking initiation (*hour* = 7). No significant change in PA was seen between 8 and 9 hours after drinking, reflecting converging PA levels across drinking and non-drinking days during this time. Slight increases were again seen, however, at 10 hours after drinking initiation.

On non-drinking days, PA showed less evidence of change throughout the day. Panel B of Figure 2 shows that PA was significantly increasing from 12 to 3 hours prior to a person's typical first drink time (*hour* = −12 to −3), with the fastest rate of increase seen 10 hours prior to typical first drink time (*hour* = −10). No significant change in PA was seen at any other point on non-drinking days.

Negative affect.—Figure 2 also shows instantaneous velocity curves for NA on drinking and non-drinking days (Panels C and D, in black and gray, respectively). On drinking days, NA started showing a steady decrease at 4 hours prior to drinking initiation (*hour* = −4). After this point, NA began to decrease at faster rates, reaching its peak at 1 hour prior to drinking (*hour* = −1). NA then continued to decrease, albeit more slowly, until 1 hour after drinking initiation (*hour* = 1), and then began to increase significantly from 3 until 7 hours after drinking initiation. This NA increase reflected a return to the level of NA observed during similar hours on non-drinking days (see Figure 1, Panel B). NA change was not statistically significant thereafter. On non-drinking days, no evidence for NA change was seen at any time point.

Question 3: Can affect levels and rates of change differentiate heavy from moderate drinking days?

Positive affect.—Figure 3, Panel A shows model-implied curves for PA on moderate drinking (gray) and heavy drinking days (black). PA was significantly higher on heavy drinking days than it was on moderate drinking days at multiple points of the day. On heavy drinking days, PA was significantly, but only slightly, *lower* than it was on moderate drinking days from - 13 to −10 hours prior to drinking initiation (*hour* = −13 to −10). PA was then significantly *higher* from 3 hours prior to drinking initiation (*hour* = −3) until 9 hours after drinking initiation (*hour* = 9). The peak of this difference was observed 4 hours after drinking initiation (*hour* = 4), where examination of the plot suggests a faster rate of decrease in PA on moderate versus heavy drinking days during this time.

Panels A and B of Figure 4 show PA derivative curves for heavy drinking days (Panel A, in black) and moderate drinking days (Panel B, in gray). On both heavy (Panel A) and moderate drinking days (Panel B), PA showed evidence of change during both the pre- and post-initiation periods, and differences in rates of change between heavy and moderate drinking days were observed at multiple times throughout the day, as marked by the dots and barbells in Panel A. Three key findings are revealed in Panels A and B of Figure 4. First, on heavy drinking days (Panel A), PA began increasing at an accelerating rate beginning 3 hours prior to the first drink, reaching peak rate of change 1 hour prior to drinking initiation (*hour* = −1), and continuing to increase, but more slowly, until drinking initiation (*hour* = 0). PA rates of change on moderate drinking days (Panel B) were significantly slower during these hours (between −4 and 0 hours relative to drinking initiation) than on heavy drinking days, and did not show evidence of acceleration, suggesting that accelerating rises in PA uniquely distinguished heavy from moderate drinking days. Second, PA continued increasing until 2 hours after drinking initiation on heavy drinking days, but on moderate drinking days, PA stopped increasing at the time of drinking initiation (*hour* = 0). Third, on both heavy and moderate drinking days, PA began to decrease a few hours after drinking started, albeit with different timing; significant decreases occurred between 3 to 7 hours post-initiation on heavy drinking days (peak decrease at 5 hours post), and between 1 and 5 hours post-initiation on moderate drinking days (peak decrease at 3 hours post). Fourth, although PA appeared to increase near the end of the day (approximately 7 to 10 hours post-initiation) on both heavy and moderate drinking days, PA increases were significant all through this interval on moderate drinking days but *not* on heavy drinking days.

Negative affect.—Figure 3, Panel B shows the model-implied time-varying NA levels on moderate drinking (gray) and heavy drinking days (black). NA was only slightly, but significantly, lower on heavy versus moderate drinking days, but this difference was significant for many hours, lasting from 6 hours prior to 7 hours after drinking initiation (*hour* = −6 to 7). The largest difference was observed 5 hours after drinking initiation (*hour* = 5), at which point NA levels appeared to gradually and approximately converge.

Panels C and D of Figure 4 show the NA velocity curves on heavy drinking (Panel C, in black) and moderate drinking days (Panel D, in gray). On both heavy (Panel C) and moderate drinking days (Panel D), NA showed evidence of change during both the pre- and post-initiation periods. Panels C and D of Figure 4 show three key findings. First, on both heavy and moderate drinking days, NA began to significantly decrease in the 4 hours prior to drinking initiation (*hour* = −4 on heavy drinking days and *hour* = −3 on moderate drinking days), and no significant differences in NA rates of change between heavy and moderate drinking days were seen prior to drinking. Thus, pre-drinking NA rates of change were not able to differentiate heavy versus moderate drinking days. Second, on heavy drinking days, NA continued decreasing until becoming non-significant at 2 hours post-initiation (*hour* = 2), whereas NA decreases became non-significant at 1 hour post-initiation on moderate drinking days (*hour* = 1); it was during these hours that NA rates of change first differed across heavy and moderate drinking days, with faster rates of decrease seen on heavy drinking days (as marked by the barbell above 1 and 2 in Figure 4, Panel C). Third, NA began to significantly *increase* post-initiation on both heavy and moderate drinking days, albeit with different timing. On heavy drinking days, NA was significantly increasing from 3 to 7 hours post-initiation (*hour* = 3 to 7), whereas on moderate drinking days, NA began increasing from 2 to 5 hours post-initiation (*hour* = 2 to 5). Fourth, significant differences in rates of change between heavy and moderate drinking days were again seen from 6 to 10 hours post-initiation, reflecting a convergence of NA levels, with NA increasing during these hours on heavy drinking days, but decreasing on moderate drinking days.

Discussion

The current study combined EMA of affect and alcohol consumption in everyday life with multilevel spline modeling, which allowed us to examine whether days of increasing drinking intensity (non-drinking, moderate, heavy drinking) could be distinguished by their patterns of affect levels and rates of change relative to drinking initiation. The following findings were revealed. First, PA levels were higher, and NA levels were lower, on drinking versus non-drinking days, both prior to and after the person's first drink. Second, rates of change in PA and NA were able to differentiate drinking versus non-drinking days, with PA showing significant and accelerating increases, and NA showing significant and accelerating *decreases*, in the hours leading up to drinking initiation on drinking days. No such change was seen on non-drinking days. Third, PA levels and changes distinguished heavy versus moderate drinking days. PA levels were higher on heavy versus moderate drinking days both before and after drinking initiation, and PA showed faster increases during the hours prior to drinking initiation on heavy versus moderate drinking days. Fourth, although NA levels were lower on heavy versus moderate drinking days, NA showed similar patterns of pre-drinking change, with only slight differences across days after drinking initiation.

Our findings add evidence to the body of literature documenting affect-drinking associations in everyday life. Regarding PA, studies generally find a positive association (Dvorak et al., 2018; Simons et al., 2010; Simons et al., 2014; Treloar et al., 2015). Regarding NA, when associations are significant, some studies report negative associations (Armeli, Conner, Cullum, & Tennen, 2010; Grant, Stewart, & Mohr, 2009; Simons et al., 2010) and some studies report positive associations (Dvorak et al., 2014; Mohr et al., 2005; Mohr, Brannan, Mohr, Armeli, & Tennen, 2008; Simons, Gaher, Oliver, Bush, & Palmer, 2005; Todd et al., 2009). Our findings agreed with previous studies showing significant positive associations between daytime PA levels and drinking, and significant negative associations between daytime NA levels and drinking.

Our findings concerning rates of change in PA and NA loosely agree with previous findings showing that daytime variability in PA and NA were associated with greater alcohol consumption (Dvorak et al., 2016; Gottfredson & Hussong, 2013). Indeed, our models generally revealed more change in both PA and NA on drinking versus non-drinking days, and on heavy versus moderate drinking days. To our knowledge, there are only a few studies that have directly operationalized affective velocity both before and after a drinking event. Perhaps the clearest comparison to our approach is a study by Crooke and colleagues (2013), which showed that among adolescents, PA was increasing before and after an "intermediate" drinking event, which they defined as consisting of between five and 10 drinks on a drinking occasion, analogous to our definition of a heavy drinking day. Our findings concerning PA rates of change prior to and after drinking loosely agree with theirs, with the key differences being (a) that their sample included adolescents (grades 9 to 11) whereas ours included adults and (b) that their modeling strategy forced the PA trajectory both before and after drinking initiation to be linear. Similarly, our finding that heavy versus moderate drinking days were not distinguished by rate of pre-drinking change in NA also loosely agree with theirs, in that they found rates of change in pre-drinking NA did not differ across days of differing drinking intensity. Our findings also build on a previous analysis of the current study data by Treloar and colleagues (2015), who used a piecewise multilevel model with linear and quadratic terms to demonstrate PA increases and NA decreases prior to and after drinking initiation. The multilevel spline modeling approach used in this paper allowed both levels and rates of change to vary continuously and in a relatively non-constrained fashion throughout time relative to drinking initiation. Our approach therefore augments theirs by allowing more nuanced modeling of the timing and magnitude of affective change across days of differing drinking intensity, thus facilitating strong tests of affect regulation models and novel information for intervention development.

Implications for theory and intervention include the following. For theory, our findings speak to the propositions of affect regulation models, which state that (a) affect is a motivator for alcohol consumption and (b) alcohol consumption is reinforcing, partly PA enhancement and NA reduction (Dvorak et al., 2018; Sher & Grekin, 2007). Regarding affect as a motivator, our findings of elevated PA and reduced NA prior to drinking initiation suggest that people tended to be in better moods on drinking days before drinking started, representing an enhancement process whereby drinking is initiated to enhance PA and continually reduce NA (Cooper, Frone, Russell, & Mudar, 1995; Sher & Grekin, 2007). Relatedly, pre-drinking PA increases and NA decreases remained significant even after adjusting for weekend versus weekday, the presence of social company, and current drinking intentions. We also observed clear evidence that the enhancement process was more pronounced on heavy versus moderate drinking days, in that (a) PA levels were higher, and NA levels were lower, and (b) PA increased at a significantly faster rate, across heavy versus moderate drinking days prior to initiation. With regard to reinforcement of drinking behavior through affect, we also found support. Our findings demonstrated that on drinking days, PA was elevated and NA was reduced after alcohol consumption, relative to non-drinking days. Derivative plots revealed that PA continued to increase and NA continued to decrease in the first few hours after drinking initiation, as would be predicted by affect regulation models, after which PA and NA levels showed a gradual return to levels that characterized non-drinking days. Finally, post-drinking PA and NA levels and PA (but not NA) rates of change were more pronounced on heavy versus moderate drinking days, suggesting a potential dose-response effect of alcohol consumption on affect.

For intervention development, our results suggest that pre-drinking affect may be a signal for heavy drinking and may inform the triggering of EMI (Heron & Smyth, 2010). EMI has been used successfully in prevention of alcohol relapse through the combination of global positioning system (GPS) sensors and smartphones (Beckjord & Shiffman, 2015). Specifically, previous studies have used intervention prompts delivered via a mobile device when the device detected that the individual was in close proximity to alcohol outlets or other areas in which they normally engaged in drinking (Gustafson et al., 2014). In this work, GPS-determined proximity to alcohol outlets served as the “trigger” for alcohol abuse risk and subsequent intervention content. Similarly, pre-drinking affective shifts could be targeted in order to prevent heavy drinking episodes, especially given that larger shifts were seen prior to higher levels of drinking. One potential downside of such an approach is that the reporting of affect is more burdensome to the participant than the passive collection of GPS data. In addition, a number of details will need to be worked out from a practical standpoint before this approach could be used effectively in an EMI. Specifically, a threshold for the size of the affective shift will need to be determined, and the number and timing of affective prompts needed to obtain sufficient information but not burden participants would need to be figured out. These details notwithstanding, our findings suggest that such an approach may offer promise regarding the development of EMI focused on preventing heavy drinking episodes.

Research considerations and future directions

Our use of EMA enhanced the ecological validity of affect reports, and our use of multilevel spline modeling allowed discovery of nuanced change patterns in affect both pre- and post-drinking initiation. Although our tests were guided by affect regulation models, we could not exactly hypothesize the specific shape of the affect curves we identified. The broad strokes of our results, however, both support and add nuance to hypotheses generated from affect regulation models, and as such may be useful in future theoretical development. Additionally, knowledge that fast increases in PA and fast decreases in NA may occur prior to drinking initiation may be useful in the planning of intervention, given adequate replication in external samples.

By nature of the EMA study design, affect reports were spaced unevenly throughout the day. As a consequence, not everyone in the sample provided affect reports during the same hours of the day, leaving some hours densely covered and others sparsely covered by participants. Over 90% of study participants were present (i.e., provided affect reports) at each of the hours between 9 hours prior to drinking initiation (hour = −9) and 3 hours after drinking initiation (hour = 3), with the rate of participation decreasing steadily as the hours moved away from these boundaries. This means that although some portions of the time axis contained a large proportion of the study sample, other parts of the time axis contained a much lower proportion. As such, when interpreting these results, the majority of interpretational weight regarding within-person processes should be given to differences observed near the drinking event (i.e., the hours between 9 hours prior to and 3 hours after drinking initiation), as the majority of individuals were present in the data during these hours. Less interpretational weight should be given to those farther away from the drinking event (outside the hours of −9 to 3), as fewer participants provided affect data in these regions. The multilevel spline modeling approach takes this into account by widening the standard errors and confidence intervals where data are sparser, as reflected in our plots. The slight differences in sample composition across time are perhaps an inherent limitation of naturalistic study designs such as EMA, and although this is addressed analytically in the current study, this issue should also be considered when interpreting similar results from EMA studies of naturalistic alcohol consumption.

A strength of our modeling approach was its ability to model complex temporal trends in affect while also adjusting estimates for the multiple levels of clustering that occur when assessments are repeated many times per day across many days, as was done in the current study. However, the complexity inherent in our modeling of time prevented us from being able to fully individualize the affect curves through random effects. When this was attempted, models would not converge. Future research might attempt curve individualization through alternate forms of estimation, including through the aggregation of individual-specific curves (a “bottom-up” approach) or through Bayesian estimation of both temporal complexity and interindividual heterogeneity (a “top-down” approach; Bringmann et al., 2017; Hamaker, Asparouhov, Brose, Schmiedek, & Muthén, 2018). Additionally, this modeling approach may be profitably adapted to examine alternative conceptualizations of dynamic relationships between alcohol and affect. For example, the biphasic alcohol effects model specifies that stimulant effects alcohol will be seen in the ascending limb, and depressant effects in the descending limb, of the blood alcohol concentration curve (Martin, Earleywine, Musty, Perrine, & Swift, 1993; Morean, Corbin, & Treat, 2013). Multilevel spline modeling could be applied to examine the changing association between consumption and affect as BAC rises and falls in EMA studies examining naturalistic drinking episodes as well as in laboratory alcohol challenge studies.

Finally, two additional issues warrant consideration. First, our results are necessarily influenced by our PANAS-based measure of affect, in which PA and NA dimensions are assumed orthogonal. Moreover, the specific items we used to operationalize PA and NA somewhat conflate valence and arousal dimensions, as all PA items indicate high arousal states (*happy*, *excited*, and *enthusiastic*) whereas NA items include a low- and high-arousal state (*sad* and *distressed*, respectively). We therefore acknowledge that our measure and approach reflect but one perspective on affect, and that approaches reflective of other affect models such as the affective circumplex model (e.g., Posner, Russell, & Peterson, 2005) may yield different insights. Second, we distinguished drinking days using NIAAA heavy versus moderate drinking day guidelines, which have been previously criticized for reasons that include a lack of clinical utility (Pearson, Kirouac, & Witkiewitz, 2016). An alternative approach that may have improved clinical utility would be to separate drinking days into those that resulted in alcohol-related consequences and those that did not. However, our assessment of alcohol-related consequences at the day-level was limited and would not support such an approach. Future research on within-day timing of affect relative to drinking may benefit from a more detailed assessment of alcohol-related consequences, allowing the stratification of affect curves by high-versus low-alcohol consequence drinking days.[2]

Conclusions

Affect regulation models suggest affect as a motivator of drinking, and drinking behavior as being reinforced through pleasurable affective change. Our results support these propositions while adding temporal nuance, suggesting that (a) accelerating increases in PA and accelerating decreases in NA preceded drinking initiation, with stronger evidence for pre-drinking PA increase seen with increasing drinking intensity; and (b) continued increases and decreases in PA and NA up to two hours after drinking was initiated, with stronger evidence for both PA and NA change seen with increasing drinking intensity. Beyond theory, these results suggest that anticipatory affect may provide a signature clue for an upcoming heavy drinking episode – which, with replication – might aid the development of future momentary intervention strategies.

[2]We did, however, assess the presence of a hangover. In the morning report, participants were asked the question: “do you have a hangover?” to which they could reply “yes” or “no”. Morning hangovers were present on 32.5% of mornings following heavy drinking days versus 7.96% of mornings following moderate drinking days, a sizable and significant difference (OR = 5.56, 95% CI: 4.21, 7.34). We then specified models testing affect curves on drinking days that eventually resulted in hangovers versus drinking days that did not result in hangover. We found remarkable similarity in these results compared to those shown in Figures 3 and 4 for heavy versus moderate drinking days. Specifically, drinking days with hangover looked similar to heavy drinking days in terms of PA and NA, and drinking days without hangover looked similar to moderate drinking days on both affects. We therefore do not include them in the current paper as they largely duplicate results for heavy versus moderate drinking days.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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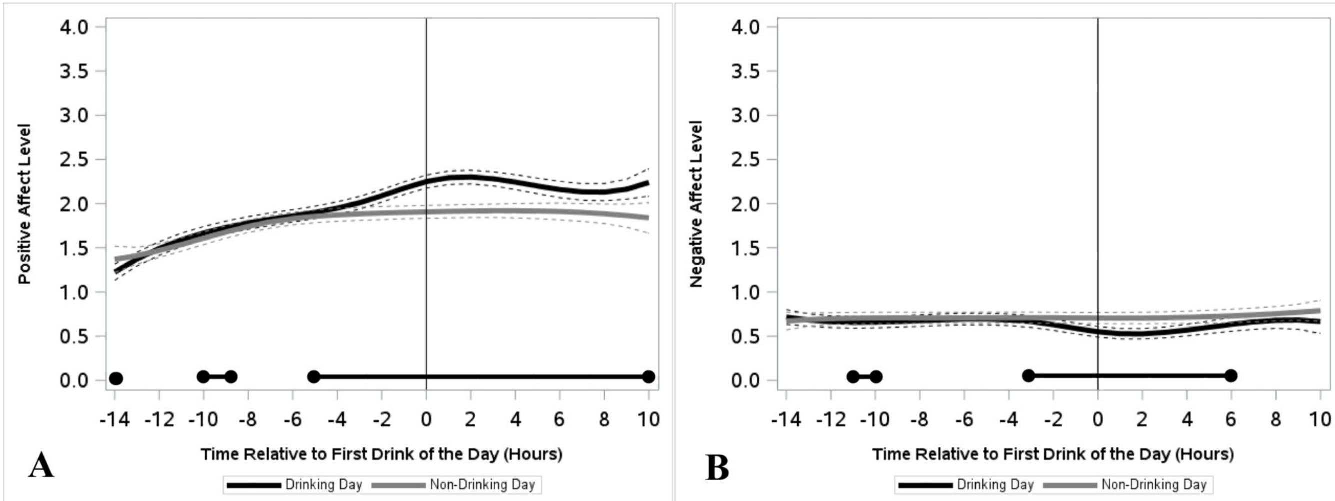

Figure 1.

Positive affect levels (Panel A) and negative affect levels (Panel B) on drinking versus non-drinking days. The vertical line intersecting with 0 on the x-axis marks the first drink time. Barbells above the time axis mark the time regions when drinking day affect levels are significantly different from affect levels during similar hours on non-drinking days.

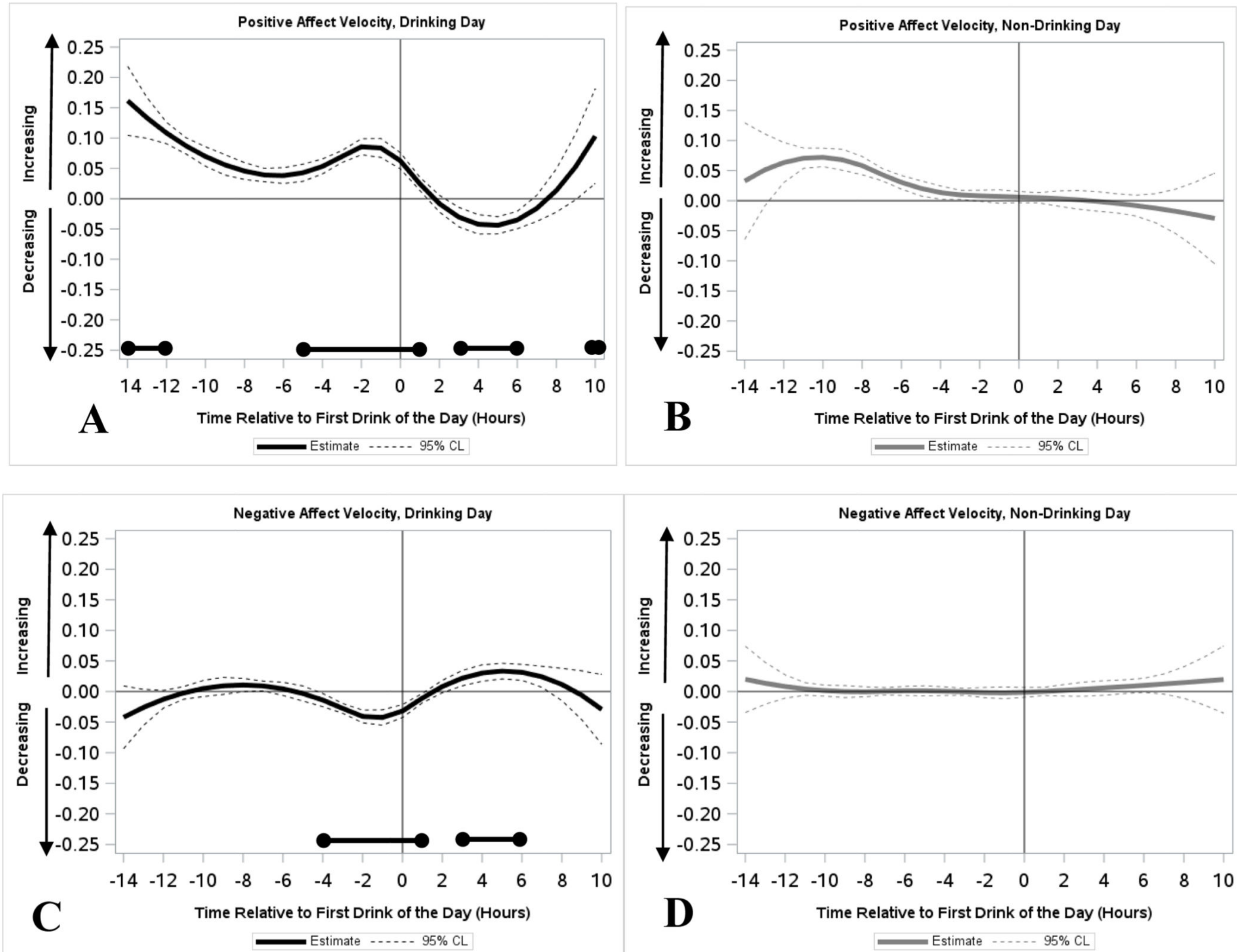

Figure 2.

Positive affect velocities on drinking days (panel A) and non-drinking days (panel B); negative affect velocities on drinking days (Panel C) and non-drinking days (panel D). Dots and barbells above the time axis mark the time regions when drinking day velocities are significantly different from velocities during similar hours on non-drinking days.

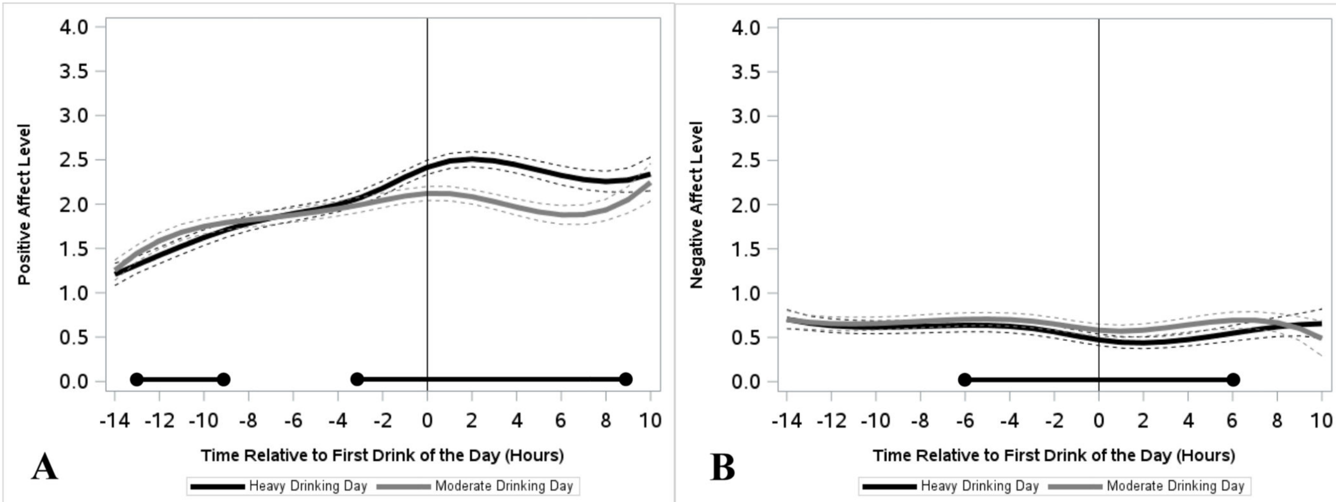

Figure 3.

Positive affect levels (Panel A) and negative affect levels (Panel B) on heavy drinking versus moderate drinking days. Barbells above the time axis mark the time regions when heavy drinking day affect levels are significantly different from moderate drinking day affect levels.

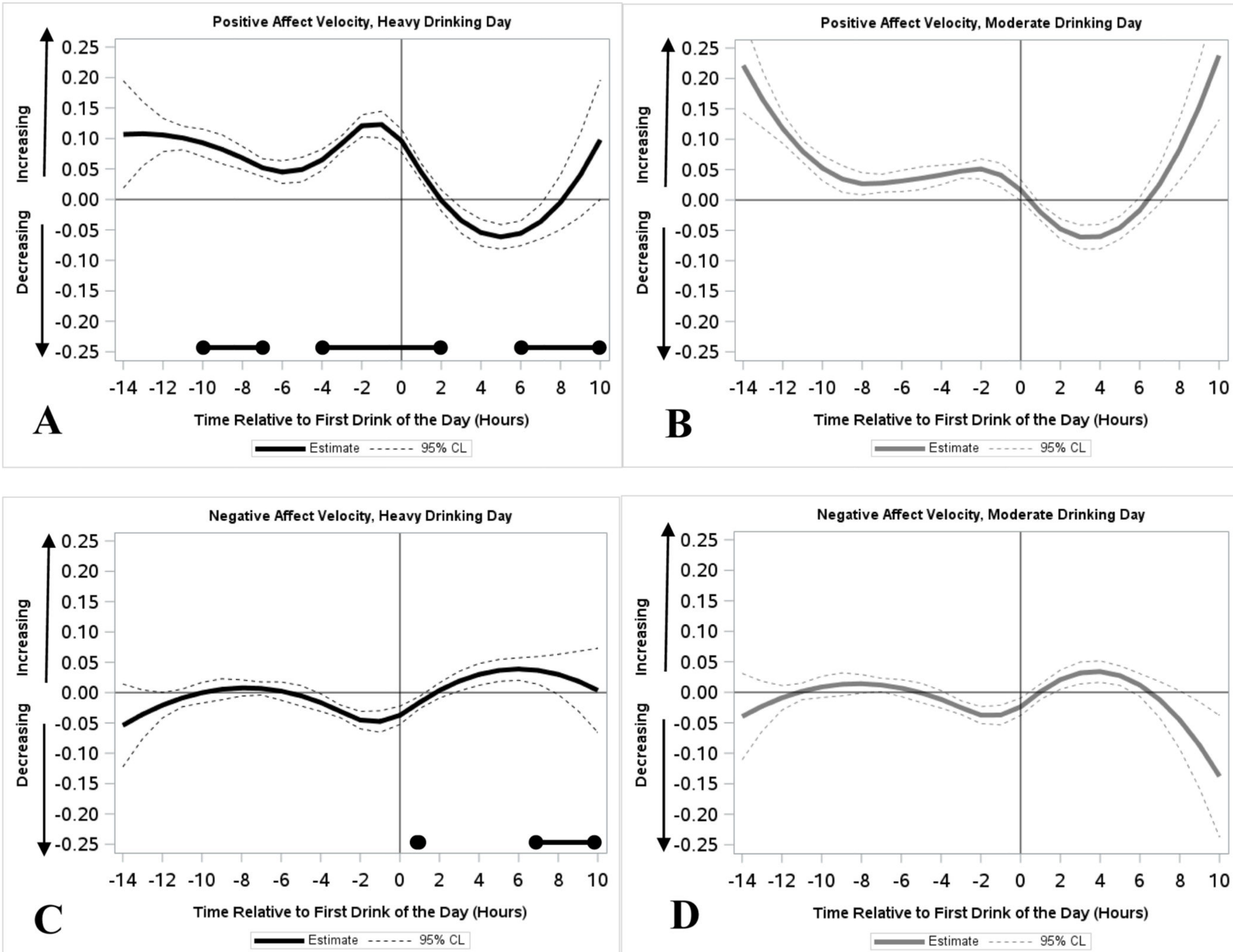

Figure 4.
Positive affect velocities on heavy drinking days (panel A) and moderate drinking days (panel B); negative affect velocities on heavy drinking days (Panel C) and moderate drinking days (panel D). Dots and barbells above the time axis mark the time regions when heavy drinking day velocities are significantly different from velocities on moderate drinking days.

Table 1.

Model fit criteria for unconditional models (time relative to first drink)

Positive Affect						
Knots (*k*)	**Deviance**	**AIC**	**BIC**	**Δ Deviance**	**Δ AIC**	**Δ BIC**
0	117166.2	117184.2	117220.2	--	--	--
1	117151.1	117171.1	117211.1	−15.1	−13.1	−9.1
2	117106.8	117128.8	117172.9	−44.2	−42.3	−38.2
3	**117058.3**	**117082.3**	**117130.3**	**−48.5**	**−46.5**	**−42.6**
4	117078.9	117104.9	117156.9	20.6	22.6	26.6
Negative Affect						
Knots (*k*)	**Deviance**	**AIC**	**BIC**	**Δ Deviance**	**Δ AIC**	**Δ BIC**
0	101379.6	101397.6	101433.6	--	--	--
1	101367.3	101387.3	101427.4	−12.2	−10.3	−6.2
2	101339.6	101361.6	101405.6	−27.8	−25.7	−21.8
3	**101323.3**	**101347.3**	**101395.4**	**−16.2**	**−14.3**	**−10.2**
4	101326.6	101352.6	101404.6	3.3	5.3	9.2

Note: Deviance is equal to −2 times the model log likelihood (−2LL).