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Daily Physical Activity and Alcohol Use Across the Adult Lifespan

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Abstract

Objective—In contrast to proposals that physical activity (PA) can be a substitute for alcohol use, people who engage in greater overall PA generally consume more alcohol on average than less-active peers. Acknowledging that both PA and alcohol use vary considerably from day-to-day, this study evaluated whether established associations reflect daily behavioral coupling within-person, are an artifact of procedures that aggregate behavior over time, or both.

Methods—A lifespan sample of 150 adults (aged 19–89 years) completed three 21-day measurement bursts of a daily diary study. At the end of each day, they reported on their PA and alcohol consumption. Data were analyzed in a negative binomial multilevel regression.

Results—As expected, both behaviors exhibited limited between-person variation. After controlling for age, sex, and seasonal and social calendar influences, daily deviations in PA were significantly associated with daily total alcohol use. Once the within-person process linking PA and alcohol use was controlled, usual PA and total alcohol use were not associated.

Conclusions—The established between-person association linking PA and alcohol use reflects the aggregation of a daily process that unfolds within-people over time. Further work is needed to identify mediators of this daily association and to evaluate causality, as well as to investigate these relations in high-risk samples.

Keywords

exercise; substance use; intraindividual; smartphone

Every year, excessive alcohol use in the United States is responsible for over 80,000 deaths and has an economic impact estimated at over \$220 billion (Bouchery, Harwood, Sacks, Simon, & Brewer, 2011; Mokdad, Marks, Stroup, & Gerberding, 2004). Alcohol use can be especially pernicious because, unlike many other health behaviors, its costs are borne by

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both users and non-users who are victimized by others' excessive consumption. Similarly, insufficient physical activity (PA) is estimated to account for 2.4% of health care costs in the United States – the equivalent of \$64.8 billion in 2011 (Centers for Medicare & Medicaid Services, 2013; Colditz, 1999). Both excessive alcohol use and insufficient PA increase risk for all-cause mortality including cardiovascular disease mortality and they interact to amplify mortality risk (Soedamah-Muthu, De Neve, Shelton, Tielemans, & Stamatakis, 2013). Consequently, interventions to modify these behavioral risk factors are high priorities for improving public health (US Burden of Disease Collaborators, 2013). For example, in the United States, Healthy People 2020 Goals for American adults include reducing average annual alcohol consumption by 10% (goal SA-16), reducing the proportion of adults who engage in no leisure-time PA (goal PA-1) and increasing the proportion of adults who meet national aerobic PA guidelines by 10% (goal PA-2) (U.S. Department of Health and Human Services, 2012).

Interventions that can modify both of these lifestyle behaviors would undoubtedly be valuable, but important questions remain that may limit intervention development. For example, although many cross-sectional studies have examined differences in alcohol use between more and less active people, longitudinal within-person associations between these health behaviors have largely been overlooked. This omission is significant because both behaviors exhibit day-to-day variation (Conroy, Elavsky, Maher, & Doerksen, 2013; Maggs, Williams, & Lee, 2011) and it is not clear whether the positive between-person association reflects a temporally-proximal behavioral coupling or is an artifact of aggregation over time. Furthermore, many more studies have focused on younger rather than older populations. Thus, it is not clear whether relations between PA and alcohol use differ across the adult life span. This study was designed to fill these critical gaps in the literature by investigating relations between daily PA and daily alcohol use in a lifespan (ages 18 to 90 years) sample of adults.

Alcohol Use and Physical Activity

Alcohol use is typically measured in terms of the number of standard servings of beer (12 fl oz), wine (5 fl oz), and liquor (1.5 fl oz) consumed. Total servings are closely linked with cumulative risk for injuries and health problems (Soedamah-Muthu et al., 2013; Taylor et al., 2010). PA is a complex health behavior that can be generally characterized by energy expenditure produced by skeletal muscles (Caspersen, Powell, & Christenson, 1985). Researchers have quantified PA with self-report measures ranging from sport participation history to some combination of the frequency, intensity, and duration of activity. A recent review of 17 studies indicated that the preponderance of available evidence points to a *positive* association between PA and alcohol use or binge drinking for youth, college students, and the general population (Piazza-Gardner & Barry, 2012). In contrast, some have proposed that aerobic PA could serve as an intervention to reduce heavy drinking because it can (a) displace time that would have been spent consuming alcohol and (b) create a similar subjective experience to alcohol use by enhancing pleasure and enjoyment, improving mood, and decreasing stress reactivity (Read & Brown, 2003). It is possible that PA may provide a substitute activity for heavy drinking populations (Brown et al., 2009; Read & Brown, 2003; Sinyor, Brown, Rostant, & Seraganian, 1982; Weinstock, 2010; Zschucke,

Heinz, & Ströhle, 2012) but, for the majority of the population who are low- or moderate-risk drinkers, these data suggest that PA interventions may be unlikely to reduce – and may even increase – alcohol use.

The vast majority of research on PA and alcohol use has been based on cross-sectional or panel research designs with self-report measures of aggregated or typical behaviors over the past 30 days or past year. These designs provide insight into between-person associations between PA and alcohol use and inform understanding of molar relations between these behaviors; however, conclusions about the processes underlying the association between behavioral aggregates may be confounded by temporal discontinuity between PA and alcohol use. For example, it is possible that people are more active during weekdays (e.g., due to occupational demands or superior time management) but consume more alcohol on weekends (e.g., because they have greater discretionary time). If that is true, it would be difficult to argue that PA and alcohol use are functionally coupled and would instead suggest that separate but related processes underlie these behaviors. This threat from behavioral aggregation is salient for PA and alcohol use because they are known to vary within-person from one day to the next (Conroy et al., 2013; Maggs et al., 2011).

Focusing on daily behavior assessed using intensive longitudinal research designs can also advance the literature by reducing the threat of biased self-reports of behavior over extended time periods (e.g., due to memory failures, reliance on heuristics; Matthews, Moore, George, Sampson, & Bowles, 2012; Schwarz, 2007). In these designs, daily data on PA and alcohol use can be aggregated to estimate each person's usual levels of each behavior. Daily deviations from an individual's usual behavior can also be calculated to reflect behavioral fluctuations. Decomposing variance in daily behaviors into these underlying components of usual and daily deviations in behavior is a useful strategy for determining whether two behaviors are functionally coupled at the daily level (i.e., a within-person association), whether their association reflects an artifact of using measures of aggregated behavior such as past 30-day recalls (i.e., a between-person association), or both. This approach has not been applied previously to study associations between PA and alcohol use.

Another factor to consider when examining relations between PA and alcohol consumption is age. PA decreases monotonically across the adult lifespan (Centers for Disease Control and Prevention (CDC), 2007). Alcohol consumption peaks between ages 21–25 years and decreases steadily thereafter (Substance Abuse and Mental Health Services Administration, 2013). Only one study has examined age-related differences in the context of past-year alcohol use and PA (Lisha, Martens, & Leventhal, 2011). In that study, vigorous PA was positively associated with alcohol use before age 50 but these behaviors were not significantly associated after age 50. Building on the idea that PA and alcohol use may be coupled at the daily level, it is not clear whether this coupling is invariant across the adult lifespan or perhaps specific to younger adults who are both more active and consume more alcohol.

The Present Study

This study was designed to extend the literature on PA and alcohol use by establishing if (a) these behaviors are coupled as a part of a within-person process that unfolds at the daily time-scale, (b) the established association is an artifact of measures that aggregate behaviors over extended time periods (reflecting a temporally-discontinuous process that appears as a between-person association), or (c) both. A second aim of the study was to evaluate whether relations between these behaviors varied as a function of age. To accomplish these aims, we employed daily diary methods to capture an extended series of behaviors in the context of participants' lives. The primary hypotheses were that (1) people who were more physically active on average would consume more alcohol (between-person association), and (2) on days when people were more active than usual, they would consume more alcohol (within-person association). It was further hypothesized that these associations would be moderated by age such that younger adults would show stronger associations between PA and alcohol use than older adults. When testing these hypotheses, we controlled for participants' sex because women tend to be less physically active and drink less alcohol than men (Substance Abuse and Mental Health Services Administration, 2013; World Health Organization, 2011), as well as within-person factors such as the time of year (i.e., month), day of week, and previous-day behavior. These within-person factors have been linked with both PA and alcohol use because of seasonal effects, the social calendar, and habitual processes so including them in the model will provide more precise estimates of typical associations between PA and alcohol use (Carpenter, 2003; Tucker & Gilliland, 2007; Uitenbroek, 1996). A multiple time-scale (measurement burst) research design was implemented to model expected within-person changes that unfold both slowly (e.g., seasonally) and rapidly (e.g., daily) (Sliwinski, 2008).

Methods

Participants

Data are drawn from the Intraindividual Study of Aging, Health, and Interpersonal Behavior (Ram et al., 2014), a study of 150 community-dwelling adults (51% women) recruited from The Pennsylvania State University and surrounding community. Purposively stratified by gender and across the adult life span, they were between 19 and 89 years of age ($M = 47.64$, $SD = 18.85$) in bins from 18–24 ($n=22$), 25–34 ($n=27$), 35–49 ($n=30$), 50–64 ($n=41$), and 65+ ($n=30$). Participants had obtained between 2 and 24 years of formal education ($M = 16.36$, $SD = 3.90$), and between 0 and 6 children ($M = 1.5$, $SD = 1.41$). Largely mirroring the local population, participants self-identified as Caucasian (91%), African American (4%), Asian American (1%), and Mixed or Other (4%) ethnicity; and as heterosexual (93%) or bisexual, gay, or lesbian (6%), with less than 1% of the participants declining to indicate sexual orientation. Participants described their employment status as full time employed (49%), retired (18%), students (15%), part-time employed (15%), or unemployed (3%). Participants' yearly family income ranged from 'under \$20,000' to '\$200,000 and over' ($Median = \text{'\$50,000 – \$74,999'}$, $Mode = \text{'\$20,000 – \$49,999'}$), with 8.7% declining to answer. Comprehensive information about the study can be found elsewhere (Ram et al., 2014). Methodological details relevant to the present study are included below.

Procedures

Participants completed three 21-day measurement bursts at regular intervals (mean interval between bursts = 124 days, SD = 38) with lab visits at the beginning and end of each measurement burst. During those lab visits, participants completed a series of web-based surveys that included demographic characteristics (distributed throughout the study to minimize burden during any single lab visit). During each 21-day measurement burst, participants used a custom smartphone survey application to provide end-of-day reports of their alcohol use and PA. In the first lab visit, a research assistant trained participants how to answer each question on the survey and specifically provided definitions of serving sizes and examples of different intensities of PA (this information was also available in the study handbook given to participants as well as in a help screen linked to those questions on the smartphone). Upon completing each daily report, participants' time- and date-stamped data were transmitted wirelessly to a secure server and backed-up locally on the phone to minimize missing data due to transmission errors. When participants returned to the lab at the end of each burst, data were downloaded from their phones to fill in any non-transmitted observations. Participants' compensation was pro-rated based on their compliance with study procedures. In total each person contributed an average of 57.1 days (SD = 12.68) of data. All procedures were approved by the institutional review board and participants provided written informed consent for all procedures prior to data collection.

Measures

Daily alcohol use was measured using three items where participants were asked to indicate the number of standard servings of beer (12 fl oz), wine (5 fl oz), and liquor (1.5 fl oz) consumed that day. The response scale included 0, 1, 2, 3, 4, and 5+ as options. Along with number of drink type-specific servings consumed, number of total servings of alcohol was calculated for each day as the sum of the three drink types.

Daily physical activity was measured using items adapted from the Leisure Time Exercise Questionnaire (Godin & Shephard, 1985). This measure was adapted from a previous-week recall to a same-day recall – an adaptation that should reduce error variance due to recall failures and reliance on heuristics (Matthews et al., 2012). Participants reported the number of 10+ min bouts of mild-, moderate-, and vigorous-intensity PA that they engaged in each day. Weights corresponding to the metabolic equivalents of each level of activity were applied (mild = 3, moderate = 5, vigorous = 9) and weighted responses were summed to create a daily PA score. Following usual practice (see Schwartz & Stone, 1998) the daily measures of PA were person-centered and split into time-invariant and time-varying components. *Usual* PA was calculated as the person-specific mean across all days, and *daily* PA deviations as day-to-day differences from those means.

Demographic characteristics were assessed using self-reports of personal (e.g., age, sex, race and ethnicity, sexual orientation, employment status, education) and family characteristics (e.g., household income, number of children). Drawing from time stamps on each record, within-person dummy variables were created for each day of the week and month of the year except Tuesday and November (which served as reference categories because they had the lowest mean alcohol consumption).

Data Analysis

Generalized multilevel models were used to accommodate the data structure with days nested within people (Snijders & Bosker, 1999) and to test hypotheses about both the within- and between-person associations between PA (daily and aggregate [usual], respectively) and alcohol use. All models were fit to the data using Mplus 5.2 (Muthén & Muthén, 1998). Although the missingness ($\ll 1\%$) mechanism was unknown, we treated incomplete data within available records as missing at random based on the null correlations between the number of days with observations and person-level scores for key study variables.

In the first step of the analysis we evaluated the utility of different distributional assumptions for accommodating the count nature of the alcohol servings variable. Specifically, we fit a series of unconditional models to participants' total servings and compared the resulting fit indices to evaluate the relative fit of models that treated the outcome variable as Gaussian, Poisson, zero-inflated Poisson, or negative binomial (Coxe, West, & Aiken, 2009; Hilbe, 2011).¹ As an example, the most complex of these, the negative binomial model, is given as

$$E(y_{it}) = \log(\mu_{it}) = \gamma_{00} + u_{0i} \quad (1)$$

where μ_{it} is the expected number of alcohol servings for person i on day t , u_{0i} are residuals that are assumed normally distributed with mean 0 and variance σ_{u0}^2 and γ_{00} is the fixed effect intercept coefficient. The number of alcohol servings for person i on day t , y_{it} , is assumed to be negative binomial distributed with a variance given by $\mu_{it} + a\mu_{it}^2$ where a is the dispersion parameter.

In the second step of the analysis (unadjusted model), we expanded the best-fitting model by adding daily and usual PA as predictors of alcohol use. For example, following the negative binomial model above, Equation 1 became

$$E(y_{it}) = \log(\mu_{it}) = \beta_{0i} + \beta_{1i}(\text{Daily PA}_{it}) \quad (2)$$

with

$$\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{Usual PA}_i) + u_{0i} \quad (3)$$

$$\beta_{1i} = \gamma_{10} \quad (4)$$

where $\gamma_{10} = \beta_{1i}$ represents the average within-person association between daily deviations in PA and alcohol use, γ_{01} represents the between-person association between usual PA (centered) and alcohol use, and β_{0i} represents average alcohol servings adjusted for daily

¹Drink-specific models were estimated and those results are available upon request from the first author.

deviations in PA. In practice, coefficients are converted to readily-interpretable incident rate ratios by exponentiation.

In the third step of the analysis (adjusted model), equations (3) and (4) were expanded to include the control variables. Specifically, previous-day PA, previous-day alcohol use, day of week (via a set of dummy variables), and season (via a set of dummy variables) were included as additional predictors in Equation 2, and age (centered), sex (0=female, 1 = male), and their two-way interactions with each other and usual PA were included as additional predictors in Equations 3 and 4.

Results

The dataset comprised 8574 daily records which represented 91% of 9450 (=150 participants $\times$ 21 days/burst $\times$ 3 bursts) possible daily records. Alcohol use data were available in 99.6% of these records. The upper portion of Table 1 shows that beer accounted for the majority of daily alcohol servings; however, zero was both the mode and median for daily consumption of all three drinks as well as total servings. Participants consumed one or more total servings of alcohol on an average of 1.91 days/week ($SD = 2.20$; mode = 0, median = 1, range = 0 – 7). The average number of daily standard servings of alcohol (beer, wine, and liquor combined across all days) was 0.66 ($SD = 1.32$; mode = 0, median = 0, range = 0 – 12). When drinking days were examined separately, participants drank an average of 2.24 total servings ($SD = 1.54$; mode = 1, median = 2). According to the definition of heavy drinking (i.e., 5 servings/day for men, 4 servings/day for women; Wechsler, Dowdall, Davenport, & Rimm, 1995), only 3.7% of the days qualified as heavy drinking days; however, 35% of participants had at least one heavy drinking day during the study.

PA data were available in 99.9% of the daily records. The lower portion of Table 1 shows that both mean scores and the proportion of between-person variation (estimated by the intraclass correlation) decreased as the intensity of activity increased. Daily PA exhibited significant positive skew (skewness = 2.66, $SE = 0.03$, $p < .05$) so a Box-Cox transformation was implemented to normalize the distribution. With $\lambda = 0.20$, the resulting skew was -0.10 .

Correlations among key study variables were estimated at the within- and between-person levels of analysis. It is best to interpret these correlations descriptively rather than inferentially because of the inherent limitations of each (i.e., within-person correlations disregard the nesting of observations within people, and between-person correlations were based on behavioral aggregates and disregard the daily fluctuations in scores for alcohol use and PA). Correlations with age and sex suggested that alcohol use was only weakly associated with greater PA (within-person $r = .03$, between-person $r = .01$) and more likely for younger adults ($r = -.06$) and men ($r = .18$). Levels of usual consumption were correlated with age, such that younger people tended to consume more beer ($r = -.25$, $p < .01$) and less wine ($r = .18$, $p < .05$) than older people, with no systematic relation between age and usual levels of liquor consumption.

The fit of an unconditional means model was estimated using a variety of distributions to characterize total servings of alcohol (i.e., Gaussian, Poisson, zero-inflated Poisson, negative binomial, or zero-inflated negative-binomial). Fit was best, as indicated by lower AIC and BIC statistics, for the negative binomial model (AIC = 15,121, BIC = 15,142) compared to the Gaussian (AIC = 25,297, BIC = 25,318), Poisson (AIC = 22,459, BIC = 22,467), or zero-inflated Poisson (AIC = 18,398, BIC = 18,412). The zero-inflated negative binomial model exhibited a similar fit (AIC = 15,063, BIC = 15,091), but did not offer sufficient improvement to justify the added complexity of differentiating two data generation processes. All subsequent analyses treated outcome variable residuals as following a negative binomial distribution.

Table 2 presents estimated parameters from the unadjusted and adjusted multilevel models of total servings of alcohol. A subset of 21 participants did not drink at all during the study but conclusions were the same whether they were included or excluded so results from the entire sample are presented. In both the unadjusted and adjusted models, people drank more on days when they were more active than usual (unadjusted $\gamma = 0.05$; adjusted $\gamma = 0.04$), and between-person differences in usual PA levels were unassociated with alcohol use. We also tested a quadratic association between these variables at both the within- and between-person levels, but these were not statistically significant and thus were not included in the final model. Daily alcohol consumption was positively associated with previous-day consumption but not with previous-day PA. Total alcohol consumption was greatest over the social weekend (Thursday through Sunday) but did not vary by season (as indicated by the month of the year). At the between-person level, age, sex, and their interactions (both with each other and with usual PA) were not associated with total alcohol consumption.

Additional analyses were conducted to evaluate whether the daily coupling of PA and alcohol consumption varied as a function of age or the day of week. Neither age nor day of week moderated associations between daily PA and alcohol consumption (all $p > .05$). Thus, the daily coupling between these behaviors appeared to be relatively uniform across slow (age) and fast (day of week) timescales. Another analysis was conducted that controlled for both the burst number (0–2) and the sequence of the day within burst (0–20); neither predictor was significant and our conclusions from the model did not change. Another set of additional analyses were conducted to predict the binary outcome of heavy episodic drinking using two versions of the dataset: one with all observed days and one with drinking days only. In both cases, PA was not associated with heavy drinking at the within- or between-person level; however, only 3.7% of total days involved heavy drinking so these results may not be conclusive. Finally, an analysis was conducted to predict the binary incident rate of drinking on a given day and findings led to conclusions that were consistent with those outlined above based on count data.

Discussion

This study provided the first evidence of a daily within-person coupling between PA and alcohol consumption across the adult life span. Results elaborated previous cross-sectional findings that recent PA and alcohol use are positively associated (Piazza-Gardner & Barry, 2012). Unlike previous work which relied on retrospective reports of behavior over an

extended period of time (e.g., past 30 days, past year), the present study documented that this association reflects a within-person process that unfolds from day-to-day and is not merely a difference between more and less active people. This finding is important because it effectively rules out the possibility that previously-reported associations have been an artifact of aggregating temporally-discontinuous behaviors, that is, that people engage in PA and drinking on separate days. Instead, people drank more than usual on the same days that they engaged in more PA than usual. This temporal proximity is relevant for future intervention design for both behaviors because a functional substitute may be needed to decouple them or reverse the direction of their coupling. Similar functional relations have been found with other health behaviors. For example, smoking cessation has been linked with increased energy intake and weight gain so nicotine replacement gum has been an effective intervention for controlling both health behaviors (Filozof, Fernández Pinilla, & Fernández-Cruz, 2004); however, more needs to be learned about the temporal sequence of and mechanism for the association between PA and alcohol use before recommending specific substitutes.

Public health goals involve both decreasing alcohol use and increasing PA (U.S. Department of Health and Human Services, 2012). Although PA has intuitive appeal as an alternative activity that could substitute for alcohol use or provide similar hedonic benefits as alcohol (Read & Brown, 2003; Weinstock, 2010), the literature does not support this approach as a universal, primary prevention strategy. A number of reasons have been offered to explain the counterintuitive, positive association which has been documented consistently, and many of those explanations have emphasized between-person differences. For example, in younger samples, sport participation is thought to increase peer influence and opportunities for experimenting with new behaviors such as alcohol use (Barber, Eccles, & Stone, 2001; Eccles & Barber, 1999; Vickers et al., 2004). Alternatively, PA and alcohol use could be influenced by common third variables such as personality factors (Rhodes & Smith, 2006; Sher, Grekin, & Williams, 2005). Unfortunately, these explanations may not be sufficient to account for the within-person process identified in the present study. A more viable explanation may be that PA and alcohol consumption have a compensatory relation (Nelson, Lust, Story, & Ehlinger, 2009). Alcohol may serve as a reward for being physically active, and PA may help to offset the caloric intake associated with alcohol use. Alcohol use may even serve a rehydration function following exercise despite its adverse effects on recovery (El-Sayed, Ali, & Ali, 2005). Alternatively, efforts to self-regulate one's PA may be ego depleting and reduce self-control for other temptations such as alcohol use (Baumeister, 2003; Christiansen, Cole, & Field, 2012). The timing of these behaviors within "active drinking days" would help to clarify temporal precedence and inform causal inferences and potential mediating pathways.

The present study identified a daily within-person process linking PA and alcohol use in a generally low- to moderate-risk population of drinkers based on contemporary criteria (National Institute on Alcohol Abuse and Alcoholism, 2010). Selective and indicated PA interventions have been proposed and evaluated for sub-populations that engage in high-risk drinking (Brown et al., 2009; Read & Brown, 2003; Sinyor et al., 1982; Weinstock, 2010; Zschucke et al., 2012). None of those studies have used intensive daily measures of activity and alcohol use so it is not clear whether an association in a high-risk sample would also

reflect a daily behavioral coupling. If it does, it will be interesting to determine if a PA intervention can either decouple or reverse the coupling of these behaviors for selected or indicated samples.

In the present study, the daily within-person process linking PA and alcohol use did not differ systematically across age or sex. Thus, it appears that the present findings were not driven by younger or male participants who tend both to engage in more PA and consume more alcohol. This finding conflicts with a previous study which reported both (a) a positive association before age 50 and no association after age 50 and (b) a stronger association for men than women (Lisha et al., 2011). That study focused on past-year vigorous PA and associations between PA and alcohol use for older adults and women may have been attenuated by their low levels of vigorous PA which would restrict the range of scores (Hallal et al., 2012). Collectively, these findings suggest an age- and sex-invariant daily process linking daily PA and alcohol use among low- to moderate-risk drinkers. Whether the daily within-person process link PA and alcohol consumption differed between people who varied in usual PA could not be determined from these data but should be considered in future research.

Temporal changes in alcohol consumption which unfolded on two separate timescales were controlled in this study. The social calendar exhibited the so-called social weekend effect on alcohol consumption (i.e., increased drinking on Thursday, Friday, and Saturday). This effect has been well-established in college student samples (Del Boca, Darkes, Greenbaum, & Goldman, 2004; Maggs et al., 2011) and this study extended that finding across the adult life span. Furthermore, despite daily differences in levels of alcohol consumption, the within-person association between PA and alcohol use did not vary according to the day of the week. This finding contrasted with previous work reporting that first-year college students who participated in sport or exercise activities on social weekends (but not on weekdays) consumed less alcohol; however, that study used a coarse measure of activity based on duration without regard to intensity or overall energy expenditure so the results are not directly comparable (Finlay, Ram, Maggs, & Caldwell, 2012).

Shifting to the slower monthly timescale, previous work using 30-day (and greater) recalls has pointed to both (a) a holiday effect whereby alcohol uses increases in December, and (b) a seasonal effect whereby heavy drinking increases in the summer (Carpenter, 2003; Uitenbroek, 1996). Strong seasonal trends were not evident in the present data which aggregated drink-specific servings into overall alcohol use in a low-risk population. We are confident that the within-person association between daily PA and alcohol use documented in this study is robust and not an artifact of seasonal variation.

Limitations of the present study establish important boundaries on the conclusions that can be drawn. First, the sample was drawn from a largely White, moderate and low-risk drinking population in central Pennsylvania so findings may not generalize broadly, and specifically to more diverse, high-risk, heavy drinking populations. Although the statistical model controlled a number of time-varying correlates of alcohol use, the non-experimental design does not permit causal conclusions from these findings. The time-varying correlates were also relatively molar and might be refined. For example, high-quality data on daily time use

would be valuable for understanding differences in alcohol use across the week. Next, both PA and alcohol use were measured subjectively through self-reports which are vulnerable to recall errors and a number of cognitive biases. If these biases originated from unmeasured individual differences, between-person associations in the model may be underestimated. Likewise, within-person associations may be threatened by the effects of alcohol itself given that reports were made at the end of each day. The PA measure focused on the frequency of PA and was relatively insensitive to other parameters (e.g., duration, mode). Objective measures of both PA and alcohol use (e.g., accelerometers, transdermal alcohol monitors) would be valuable for future research. Also, this study focused on servings of alcohol and measures such as estimated blood alcohol content may be more directly related to risk. Finally, we speculated about mechanisms for the observed association but these mechanisms were not tested in the present research.

In closing, this study provided the first evidence of a daily within-person coupling between PA and alcohol consumption across the adult lifespan. This finding was driven largely by beer consumption, and was uniform across the entire week, despite changes in the amount of alcohol consumed on the social weekend. Future work should build on these findings by investigating the mechanisms and direction of causality underlying the association, and investigating heavy drinking populations. These findings point to the need for interventions that can target both PA and alcohol use and highlight some of the barriers that intervention scientists must overcome to meet that challenge.

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Table 1

Descriptive statistics for daily alcohol use and physical activity

	M	SD	Median	Mode	Range	% Days Zero	ICC
<i>Alcohol Use</i>							
Total servings	0.66	1.32	0	0	0 – 12	70.2%	.40
Beer	0.32	0.88	0	0	0 – 5	83.7%	.31
Wine	0.21	0.68	0	0	0 – 5	87.8%	.47
Liquor	0.14	0.54	0	0	0 – 5	91.6%	.21
<i>Physical Activity</i>							
Light	1.47	1.49	1	0	0 – 10	29.5%	.40
Moderate	0.77	1.12	0	0	0 – 10	56.4%	.27
Vigorous	0.35	0.80	0	0	0 – 10	76.3%	.21
Total (raw)	11.46	12.46	8	0	0 – 170	19.4%	.33
Total (transformed)	2.63	1.68	2.76	0	0.00 – 8.98	19.4%	.40

Note. Nobservations = 8557 daily reports provided by 150 persons. Total (transformed) score for physical activity used a Box-Cox power law transformation with $\lambda = 0.20$. ICC = intraclass coefficient (proportion of variance in the repeated measures attributed to between-person differences).

Table 2
Negative binomial multilevel model coefficients examining associations between physical activity and daily total servings of alcohol

	Unadjusted Model			Adjusted Model		
	γ	SE	IRR	γ	SE	IRR
Intercept	-1.43**	0.16	0.24	-2.16**	0.43	0.11
Daily physical activity	0.05*	0.02	1.05	0.04*	0.02	1.04
Usual physical activity	0.20	0.14	1.22	0.07	0.19	1.07
Previous-day alcohol ^a				0.06**	0.02	1.06
Previous-day physical activity				0.00	0.02	1.00
Sunday				0.25**	0.09	1.28
Monday				0.13	0.08	1.14
Wednesday				0.12	0.08	1.13
Thursday				0.34**	0.09	1.41
Friday				0.77**	0.10	2.17
Saturday				0.88**	0.11	2.42
January				0.13	0.13	1.14
February				0.10	0.14	1.11
March				0.02	0.11	1.02
April				-0.11	0.09	0.90
May				0.16	0.11	1.18
June				0.08	0.09	1.09
July				0.15	0.14	1.17
August				0.15	0.12	1.16
September				0.24	0.20	1.27
October				0.16	0.10	1.17
December				-0.04	0.12	0.96
Age				-0.02	0.02	0.98
Sex				0.99	0.68	2.70
Age $\times$ Sex				-0.01	0.02	1.00
Age $\times$ Usual physical activity				-0.01	0.01	0.99

	Unadjusted Model			Adjusted Model		
	γ	SE	IRR	γ	SE	IRR
Sex $\times$ Usual physical activity				0.18	0.27	1.20
Dispersion, α	0.59**	0.19		0.44**	0.15	
Random effects, σ^2_{uo}	3.03**	0.46		2.60**	0.43	

** p < .01,
* p < .05.

^dPrevious-day alcohol represented the lagged outcome variable (i.e., total servings). IRR = Incident Rate Ratio.