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Reduced Impact of Alcohol Use on Next-Day Tiredness in Older Relative to Younger Adults: A Role for Sleep Duration

David M. Lydon-Staley
The Pennsylvania State University

Nilam Ram
The Pennsylvania State University and German Institute for Economic Research, Berlin, Germany

Annette Brose
Humboldt University Berlin and The KU Leuven

Florian Schmiedek
Max Planck Institute for Human Development, Berlin, Germany, and German Institute for International Educational Research, Frankfurt am Main, Germany

Recent work has suggested that older adults may be less susceptible to the next-day effects of alcohol relative to younger adults. The effects of alcohol in younger adults may be mediated by sleep duration, but due to age differences in the contexts of alcohol use, this mediation process may not generalize to older adults. The present study examined age-group (younger vs. older adults) differences in how alcohol use influenced next-day tiredness during daily life. Reports of alcohol use, sleep duration, and next-day tiredness obtained on ~101 days from 91 younger adults (ages 20–31 years) and 75 older adults (ages 65–80 years) were modeled using a multilevel, moderated mediation framework. Findings indicated that (a) greater-than-usual alcohol use was associated with greater-than-usual tiredness in younger adults only, (b) greater-than-usual alcohol use was associated with shorter-than-usual sleep duration in younger adults only, and (c) shorter-than-usual sleep duration was associated with greater tiredness in both younger and older adults. For the prototypical younger adult, a significant portion (43%) of the association between alcohol use and next-day tiredness could be explained assuming mediation through sleep duration, whereas there was no evidence of mediation for the prototypical older adult. Findings of age differences in the mediation process underlying associations among alcohol use, sleep, and tiredness provide insight into the mechanisms driving recent observations of reduced next-day effects of alcohol in older relative to younger adults.

Keywords: sleep, alcohol, age differences, tiredness, within-person mediation

The experience of next-day tiredness is one of the more commonly reported residual symptoms of alcohol use (Penning, McKinney, & Verster, 2012). Alcohol administration has led to next-day tiredness in controlled, laboratory settings (Chait & Perry, 1994; Howland et al., 2008; Rohsenow et al., 2007), with the association between alcohol use and next-day tiredness also recently having been observed during day-to-day life using an intensive repeated-measures design (Patrick, Griffin, Huntley, & Maggs, 2016). Although the next-day effects of alcohol are thought to be magnified in older adults due to age-related changes in how the body metabolizes alcohol (Blow, 1998; Meier & Seitz, 2008; Vestal et al., 1977), few studies have investigated these age differences. Emerging evidence has indicated that the next-day effects of alcohol may instead be reduced in older adults relative to younger adults (Tolstrup, Stephens, & Grønbaek, 2014). The present study examined age-group differences—younger adults (ages 20–31 years) versus older adults (age 65–80)—in the within-subject associ-

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David M. Lydon-Staley, Department of Human Development and Family Studies, The Pennsylvania State University; Nilam Ram, Department of Human Development and Family Studies, The Pennsylvania State University, and German Institute for Economic Research, Berlin, Germany; Annette Brose, Institute of Psychology, Humboldt University Berlin, and Faculty of Psychology and Educational Sciences, The KU Leuven; Florian Schmiedek, Center for Life Span Psychology, Max Plank Institute for Human Development, and German Institute for International Educational Research, Frankfurt am Main, Germany.

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Correspondence concerning this article should be addressed to David M. Lydon-Staley, who is now at Department of Bioengineering, University of Pennsylvania, 210 South 33rd Street, Suite 240 Skirkanich Hall, Philadelphia, PA 19104-6321. E-mail: dlsta@seas.upenn.edu

ation between alcohol use and next-day tiredness and whether these differences may be explained by differences in sleep.

Next-Day Tiredness: The Role of Sleep Across Age

Generally, sleep serves a restorative function (Zisapel, 2007). However, when sleep patterns are disrupted, the restorative function of sleep is undermined. In particular, experience of tiredness or fatigue is more likely after reduced levels of Stage 3 deep sleep (Thomas, Bardwell, Ancoli-Israel, & Dimsdale, 2006), after fragmented sleep (Moore, Bardwell, Ancoli-Israel, & Dimsdale, 2001), and when individuals self-report poorer sleep quality (Kaynak et al., 2006) or lower-than-usual sleep duration (Kamdar, Kaplan, Kezirian, & Dement, 2004; Patrick et al., 2016). Sleep duration and quality have been observed to decrease with age (Floyd, Janisse, Jenuwine, & Ager, 2007; Lemola & Richter, 2012). Older adults have exhibited more awakenings and reduced amounts of slow-wave sleep relative to younger adults (Conte et al., 2014; Van Cauter, Leproult, & Plat, 2000). Health status is an important factor underlying changes in sleep observed across age (Bliwise, 1993; Luca et al., 2015), but normative, biological changes also play a role. In particular, findings that sleep duration decreases and nighttime awakenings tend to increase with age suggest that older adults have lower sleep needs (e.g., Dijk, Groeger, Stanley, & Deacon, 2010). The homeostatic pressure to sleep is regulated by increases in extracellular levels of the neuromodulator adenosine, which during waking hours are thought to facilitate the transition from wake to sleep by inhibiting activity in the cholinergic basal forebrain (Basheer, Strecker, Thakkar, & McCarley, 2004; Thakkar, Winston, & McCarley, 2003). There is a loss of adenosine A1 receptors with age (Cheng, Liu, Juang, & Jou, 2000; Ekonomou, Pagonopoulou, & Angelatou, 2000), implying that older adults have reduced sensitivity to increasing adenosine concentrations and, thus, experience lower sleep pressure (Mander, Winer, & Walker, 2017), which manifests as shorter sleep durations, even when older adults are provided with long periods of sleep opportunity (Klerman & Dijk, 2008).

Despite some evidence for lower sleep pressure in older relative to younger adults, both sleep duration and quality remain important predictors of daytime fatigue as people age (Alapin et al., 2000; Goldman et al., 2008). Sleep duration is still related to next-day cognitive and affective functioning in older adults (Gamaldo, Allaire, & Whitfield, 2010; McCrae et al., 2008). This has led some researchers to suggest that, rather than reflecting lower sleep need in older adults, shorter sleep duration and continued vulnerability for sleep-deprivation-associated next-day impairments in cognitive functioning may reflect an impaired ability to register or generate unmet sleep needs (Mander et al., 2017). In sum, even in the context of age-related changes in typical levels of sleep duration and quality, within-subject variability in sleep remains important for next-day functioning in older adults.

Age Differences in the Association Between Alcohol and Next-Day Tiredness

Alcohol use is thought to lead to tiredness due, at least partially, to its detrimental effects on sleep (Rohsenow, Howland, Minsky, & Arnedt, 2006). Although alcohol shortens sleep-onset latency (Williams, MacLean, & Cairns, 1983), alcohol is also associated with poorer quality sleep (Rohsenow et al., 2010). Laboratory studies have found that sleep is shallower and more fragmented in the second half of the night after consuming alcohol than after consuming a placebo (Feige et al., 2006; Landolt, Roth, Dijk, & Borbély, 1996). Similarly, in situ studies of individuals' day-to-day life have also found that individuals have decreased sleep quality and/or sleep duration after alcohol use (Galambos, Dalton, & Maggs, 2009; Lydon et al., 2016; Patrick et al., 2016).

Age-related changes in physical composition and functioning—including decreases in lean body mass and body water volume (Vestal et al., 1977) and decreased metabolism of alcohol (Meier & Seitz, 2008)—influence how older adults respond to alcohol (see Blow, 1998). In the hour following oral administration of alcohol, older adults have higher blood alcohol concentrations than do younger adults (Gärtner, Schmier, Bogusz, & Seitz, 1996). In animal models, older relative to younger animals have higher ethanol levels in the brain and blood in the hours following alcohol administration (Wiberg, Trenholm, & Coldwell, 1970) and show increased residual symptoms of alcohol (Brasser & Spear, 2002).

Despite these laboratory-based findings, remarkably little research has examined potential age differences in the severity of effects of alcohol on next-day functioning in humans. One of the few studies examining age differences in the next-day effects of alcohol use, a cross-sectional survey of men and women ages 18–84, observed that hangover symptoms following binge drinking were more common in younger age groups than in older age groups (Tolstrup et al., 2014), with those age differences not explained by differences in individuals' usual amount of alcohol consumption or frequency of binge drinking. The finding that older adults have fewer hangover symptoms than do younger adults does not align with the laboratory or animal research. This discrepancy may be due to a variety of real-world compensatory processes unavailable in the tightly controlled laboratory setting, including the use of strategies to avoid hangovers, greater experience with and biological tolerance for alcohol, and natural selection processes that reduce the population of older drinkers to those who experience the least severe residual effects of alcohol.

Age Differences in the Association Between Alcohol and Sleep Duration

One difference between laboratory and real-world alcohol use that may drive age-related differences in the residual effects of alcohol use is age-related differences in the association between alcohol use and sleep duration. In the laboratory, alcohol impacts sleep quality but not sleep duration (MacLean & Cairns, 1982; Yules, Freedman, & Chandler, 1966). In the laboratory studies, however, there were few constraints on sleep duration, and participants were able to get a full night of sleep. Outside the laboratory, in contrast, alcohol use and sleep deprivation are often experienced together with work, family, and other demands potentially constraining the possibility for longer sleep duration after alcohol use (Verster, 2008). And, these demands likely differ systematically with age. Generally, daily demands tend to decrease with older age because family and work duties decrease (e.g., after retirement). Younger adults have reported more frequent work, interpersonal, and home stressors relative to older adults (Charles et al., 2010; Neupert, Almeida, & Charles, 2007). These age-related differences in daily life contexts, together with changes in priorities and motivations, have implications for leisure time and may lead to greater regularities in the daily routines of older adults relative to younger adults (Brose, Scheibe, & Schmiedek, 2013; Carstensen, Isaacowitz, & Charles, 1999; Lieberman, Wurtman, & Teicher, 1989).

There has been increasing evidence that the greater regularity in daily routines observed in older relative to younger adults extends to sleep behaviors. In daily diary studies that track sleep behavior over multiple days, older adults have shown more consistent sleep routines than have younger adults, with less day-to-day variability in total sleep time (Dillon et al., 2015; Shoji, Tighe, Dautovich, & McCrae, 2015), as well as bed in-time and bed out-time (Kramer, Kerkhof, & Hofman, 1999). The increased regularity in sleep schedules among older adults may have implications for sleep duration following alcohol use. Older adults tend to use alcohol at meal times or as an activity to bring the day to a close, to drink at home, and to drink alone (Burruss, Sacco, & Smith, 2015; Sacco et al., 2015). In contrast, the alcohol use of younger adults occurs more frequently in public rather than private places (Grønkjær, Vinther-Larsen, Curtis, Grønbæk, & Nørgaard, 2010; Wells, Graham, Speechley, & Koval, 2005). These age differences in the context of alcohol use (e.g., alcohol use at bars and discos vs. drinking at home), alongside the more general tendency for older relative to younger adults to maintain consistent routines, may render younger adults more susceptible to reductions in sleep duration when they use alcohol and, in turn, more susceptible to the experience of next-day tiredness. In sum, age differences in the association between alcohol use and tiredness, whereby older adults experience less marked effects of alcohol use on tiredness, may result from age differences in the association between alcohol and sleep duration.

Within-Subject Theory, Study Design, and Analysis

Notably, this hypothesis is about between-subjects (i.e., age group) differences in within-subject associations (e.g., on days when sleep duration is shorter than usual, tiredness will be greater than usual). This focus on within-subject processes necessitates the use of intensive longitudinal designs that facilitate the capture of day-to-day fluctuations in the behaviors of interest (Molenaar, 2004; Ram & Gerstorf, 2009). In particular, experience-sampling methods, whereby individuals regularly report about their daily lives for substantial periods of time (e.g., 100 days) provide opportunity to both articulate and test how specific within-subject processes unfold outside the laboratory (e.g., Bolger, Davis, & Rafaeli, 2003; Larson & Csikszentmihalyi, 1983; Shiffman, Stone, & Hufford, 2008). Once collected, such data can be examined using analytic frameworks that appropriately disambiguate within- and between-subjects effects (Bolger & Laurenceau, 2013). Particularly useful are multilevel modeling frameworks that account for the nesting of repeated measures within subjects and allow for examination of between-subjects differences in within-subject associations (Snijders & Bosker, 2012). Extensions of these models allow for examination of within-subject mediation (Bauer, Preacher, & Gil, 2006) and between-subjects differences in within-subject variability (Hedeker, Mermelstein, & Demirtas, 2012; Hoffman, 2007). Applied to intensive longitudinal data collected from both younger and older adults, these models provide for elegant testing of age differences in within-subject processes.

The Present Study: Age Differences in How Sleep Duration Mediates the Association Between Alcohol and Next-Day Tiredness

Using intensive longitudinal data, we examined age-group differences in within-subject associations among alcohol use, sleep duration, and tiredness. A schematic of the inquiry is shown in Figure 1. Following from findings of greater tiredness after alcohol use (Patrick et al., 2016), we hypothesized that on days when individuals used more alcohol than usual, they would experience greater-than-usual next-day tiredness ($c' > 0$). Following from findings of shorter sleep duration following alcohol use (Kamdar et al., 2004), we hypothesized that this association would be mediated by sleep duration. That is, we hypothesized that the association between alcohol use and next-day tiredness would be accounted for by a path where greater-than-usual alcohol use would lead to shorter-than-usual sleep duration (a_i) and, in turn, to next-day tiredness (b_i). It is important to note that the effects of alcohol use on both tiredness and sleep duration were hypothesized for younger but not older adults (Dillon et al., 2015; Grønkjær et al., 2010; Tolstrup et al., 2014), but, given the continued relevance of sleep duration in tiredness at older ages (Alapin et al., 2000), it was hypothesized that both younger and older adults would experience increases in tiredness following nights of shorter-than-usual sleep duration (b_i). Finally, following the proposition that there is greater inconsistency in routines among younger adults, we expected that older adults would exhibit less variability in sleep and tiredness relative to younger adults. Specifically, fluctuations in sleep duration and next-day tiredness (i.e., in e_M, e_Y) were allowed to differ across age groups. In sum, the present study leveraged intensive repeated-measures data and multilevel mediation models to provide further insight into the recent finding that the next-day effects of alcohol were decreased in older relative to younger adults (Tolstrup et al., 2014) by examining age-group differences in the path between alcohol use, sleep duration, and next-day tiredness.

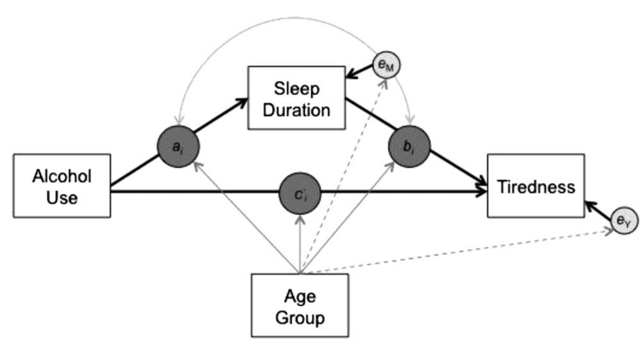

Figure 1. A simplified schematic of the multilevel, moderated mediation (1–1–1) model with heterogeneous variance. Alcohol use, sleep duration, and tiredness are person-centered day-level repeated-measures variables. Age group is a person-level variable. The solid arrows from age group to a_i, b_i, and c_i' indicate that the within-subject associations among alcohol use, sleep duration, and tiredness may be moderated by age group, and the dashed arrows from age group to the residuals of sleep duration and next-day tiredness indicate that the variance of these residuals may also differ between age groups.

Method

The present study made use of data from the COGITO Study, an intensive longitudinal study designed for the examination of day-to-day intraindividual variability across a range of domains, including cognition, stress, affect, and health (Brose, Schmiedek, Lövdén, & Lindenberger, 2011; Wolff et al., 2012). Detailed information on the larger study is available in Schmiedek, Lövdén, and Lindenberger (2010). The ethical review board of the Max Plank Institute for Human Development approved the study.

Participants and Procedure

Participants were 101 younger (51.5% women; ages 20–31) and 103 older (49.5% women; ages 65–80) adults recruited through newspaper advertisements, word-of-mouth recommendations, and fliers circulated in Berlin, Germany (see Schmiedek et al., 2010). After being recruited into the study and going through a 10-day run-in and pretesting period, participants began a microlongitudinal module wherein they were asked to report to the laboratory three or more times per week at times of their choosing (between 8:00 a.m. and 8:30 p.m., Monday through Saturday) to complete a short battery of questionnaires and cognitive tests (about 1 hr). As part of the daily assessment, participants provided information about their current and prior day's activities, feeling states, and behaviors (e.g., sleep).

With interest in the within-subject associations among daily alcohol use, sleep duration, and tiredness, the analysis sample was limited to those participants who reported using alcohol on at least one day throughout the 100-day phase. Specifically, we set aside data from the $n = 10$ younger and $n = 28$ older adults with zero alcohol use (abstainers). The group of younger adult abstainers did not differ from their drinking peers on average sleep duration, $t(99) = .53$, $p = .60$; tiredness, $t(99) = -.54$, $p = .59$; or number of days in the study, $t(99) = .47$, $p = .64$. Similarly, the group of older adult abstainers did not differ from their drinking peers on average sleep duration, $t(101) = -1.25$, $p = .22$, or number of days in the study, $t(101) = -1.01$ $p = .32$. However, the older abstainers did have significantly higher average levels of tiredness ($M = 2.77$, $SD = 1.12$) than did their drinking peers ($M = 2.19$, $SD = .93$), $t(101) = 2.66$, $p = .02$. After we removed the abstainers, complete data was available for 16,598 (99.3%) of 16,725 possible days, nested within $n = 91$ younger persons (mean years of education = 12.44, $SD = 1.35$) and $n = 75$ older persons (mean years of education = 10.95, $SD = 1.75$) that each provided on an average of 100.79 days ($SD = 2.62$, range = 87–109) and 101.13 days ($SD = 2.50$, range = 90–106), respectively. Notably, a similar pattern of findings was obtained when these abstainers were included in the analysis.

Measures

The present study made use of younger and older adults' reports of alcohol use, sleep duration, and tiredness obtained in the ~100-session microlongitudinal battery.

Alcohol use. Individuals' alcohol use was measured at each session as the total amount (in liters) of alcohol consumed within the previous 24 hr. Using a graphical user interface, participants completed an alcohol consumption grid. Pictures of alcoholic drinks (including beer, wine, and liquor and their associated alcohol content) were placed around the outside of a grid. Participants were instructed to drag pictures of all the drinks they had consumed within the last 24 hr and drop them into the grid. Each of the drink icons could be dropped into the grid as many times as necessary as a counter (visible to participants) kept track of the total alcohol that had been added to the grid. *Alcohol use* was computed in liters from this grid for each participant for each day and converted to number of standard drinks (14 g or milliliters of alcohol = 1 drink). On average, younger adults consumed .64 drinks per day ($SD = 1.48$, range = 0–16.91) and older adults consumed .61 drinks per day ($SD = .95$, range = 0–11.27). On average, the proportion of days that younger adults consumed alcohol was .26 ($SD = .18$) and that older adults did was .39 ($SD = .32$).

Sleep duration. Previous night's sleep duration was measured at the beginning of each session (after the assessment of alcohol use and before the cognitive tasks) as response to the item "How many hours did you sleep last night?" with an open response format where the participants could enter hours and minutes. On average, younger adults slept for 7.20 hr ($SD = 1.48$, range = 0–14) and older adults slept for 7.06 hr ($SD = 1.11$, range = 0–13).

Next-day tiredness. At each session, individuals' level of tiredness was measured (before the cognitive tasks) as the response to the item "How tired/fresh do you feel right now?" with responses provided on an 8-point scale ranging from 0 (*very tired*) to 7 (*very fresh*). The item was reverse-scored ($7 - y$) so that higher scores indicated greater tiredness. On average, across all days, average level of tiredness was $M = 3.29$ ($SD = 1.39$, range = 0–7) for the younger adults and $M = 2.19$ ($SD = 1.17$, range = 0–7) for the older adults. To emphasize the differences in the temporal frames of the tiredness and alcohol use assessments, we refer to the tiredness variable as *next-day tiredness*.

Age group. Age group was coded as a binary variable: younger adult (20–31) = 0 and older adult (65–80) = 1.

Data Analysis: Moderated Multilevel (1–1–1) Mediation Model With Heterogeneous Variance

Our main interest was to examine age differences in how sleep duration may mediate the within-subject association between alcohol use and next-day tiredness. Taking advantage of and accommodating the nested nature of the microlongitudinal data (16,598 days nested within 166 persons), we examined hypotheses within a multilevel modeling framework (Snijders & Bosker, 2012) using a moderated within-subject (1–1–1) mediation model (Bauer et al., 2006). To focus the analysis on within-subject associations, we conceived all three variables of interest as having time-invariant and time-varying components and split accordingly (Bolger & Laurenceau, 2013). For example, the repeated measures of next-day tiredness were split into a person-level, time-invariant variable that was calculated as the within-subject mean across the repeated measures and a day-specific, time-varying variable that was calculated for each day as the deviation in next-day tiredness from the person-specific mean. Figure 2 illustrates the time-varying alcohol use, sleep duration, and next-day tiredness variables of a prototypical younger adult (gray continuous line) and a prototypical older adult (black continuous line). Days on which the continuous lines are above the dotted line at zero are days of more-than-usual levels of alcohol use, sleep duration, or next-day tiredness for that individual. Days on which the continuous lines are below the dotted line at zero are days of less-than-usual levels of alcohol use, sleep duration, or next-day tiredness. Immediately apparent in the figure are differences in overall variability between these persons (a point we return to later). After splitting, the three time-invariant components (stable between-subjects differences) were set aside and the three time-varying components (day-to-day within-subject changes) were examined using a multilevel mediation model of the form shown in Figure 1.

In brief, the within-subject (1–1–1) mediation models are conceived as two Level 1 regression equations: one where the mediator variable, $M_{it} = sleepduration_{it}$, is regressed on the causal variable, $X_{it} = Alcohol_{it}$,

$$Sleepduration_{it} = 0 + a_i\,Alcohol_{it} + e_{Mit} \quad (1)$$

and one where the outcome variable, $Y_{it} = Tiredness_{it}$, is regressed on the mediator variable, M_{it}, and the causal variable, X_{it},

$$Tiredness_{it} = 0 + b_i\,Sleepduration_{it} + c_i'\,Alcohol_{it} + e_{Yit}, \quad (2)$$

where a_i, b_i, and c_i' are person-specific regression coefficients that indicate the unique within-subject associations, and the zero is included to make explicit that between-subjects differences in baseline levels were set aside. The person-specific coefficients are modeled at Level 2 as a function of between-subjects differences in age group. Specifically,

$$a_i = \gamma_{a0} + \gamma_{a1}Agegroup_i + u_{ai}, \quad (3)$$

$$b_i = \gamma_{b0} + \gamma_{b1}Agegroup_i + u_{bi}, \text{ and} \quad (4)$$

$$c_i' = \gamma_{c'0} + \gamma_{c'1}Agegroup_i + u_{c'i} \quad (5)$$

where γ_{a0}, γ_{b0}, and $\gamma_{c'0}$ indicate the prototypical within-subject associations among the three variables for a younger adult; γ_{a1}, γ_{b1}, and $\gamma_{c'1}$ indicate age-group differences in the prototypical within-subject associations, and u_{ai}, u_{bi}, and $u_{c'i}$ are residual unexplained between-subjects differences in the extent of within-subject associations that are assumed normally distributed with zero means and a full covariance structure, $\sim N(0, \sum_G)$.

It is important to note that the within-subject residuals, e_{Mit} and e_{Yit}, are also assumed to be normally distributed with zero means and person-specific variances, σ^2_{eMi} and σ^2_{eYi}, that may also differ across age group. Formally, the model accommodated heterogeneous variances such that

$$\sigma^2_{eMi} = \alpha_{0M}\left[\exp(\alpha_{1M}Agegroup_i)\right] \text{ and} \quad (6)$$

$$\sigma^2_{eYi} = \alpha_{0Y}\left[\exp(\alpha_{1Y}Agegroup_i)\right], \quad (7)$$

where α_{0M} and α_{0Y} indicate the prototypical residual within-subject variance for the mediator and outcome variables for the young group and α_{1M} and α_{1Y} indicate the difference in those variances between age groups.

In practice, Equations 1 through 7 are combined and estimated simultaneously in a single multilevel model with heterogeneous variances using data that are restructured so that the two outcome variables (mediator $M_{it} = sleepduration_{it}$ and outcome $Y_{it} = tiredness_{it}$) are collected into a single repeated-measures variable, Z_{it}, along with dummy indicators, S_{mi} and S_{yi}, that indicate whether the specific observation of Z_{it} belongs to the mediator or outcome

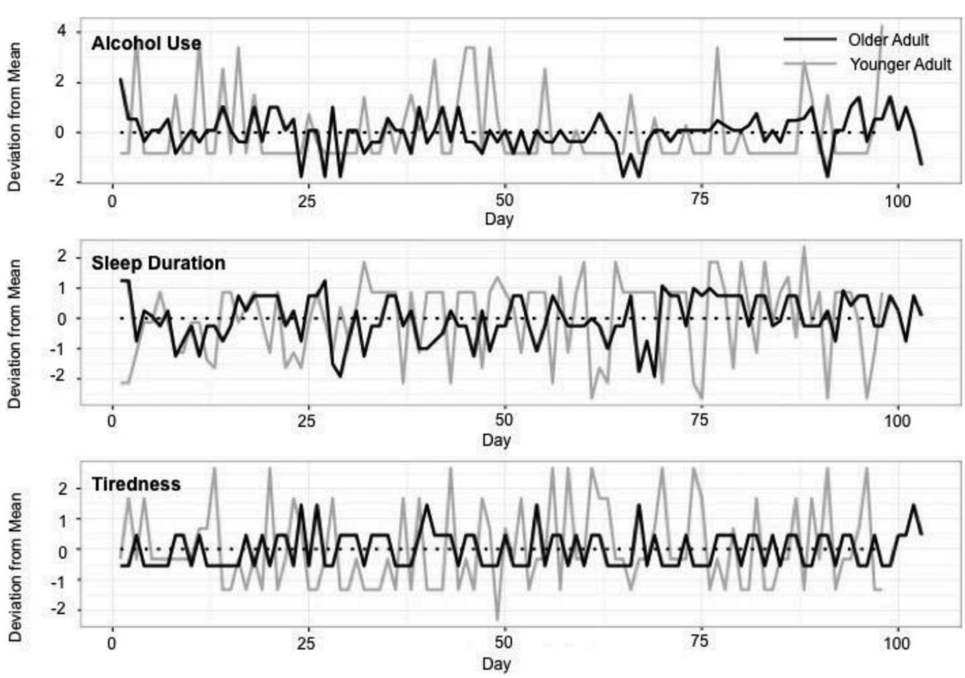

Figure 2. An illustration of the trivariate, intensive-repeated data for a younger adult (gray solid line) and an older adult (black solid line). The continuous lines indicate changes in alcohol use (top panel), sleep duration (middle panel), and next-day tiredness (bottom panel) across days along the *x*-axis, relative to each participant's person-specific, time-invariant means, which are indicated by the dotted lines at zero along the *y*-axis.

variable and that serve to "turn on" and "turn off" specific parameters for each row in the data (see Bauer et al., 2006; Bolger & Laurenceau, 2013; McCallum, Kim, Malarkey, & Kiecolt-Glaser, 1997). Using this setup, all models were estimated using SAS 9.3 PROC MIXED (Littell, Milliken, Stroup, & Wolfinger, 2006).

Model parameters were then used to test for age-group differences in extent of within-subject mediation (MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002). Specifically, (following Bauer et al., 2006) the conditional expected value of the indirect and direct effects was calculated as

$$E(a_i b_i | W_i = w) = (\gamma_{a0} + \gamma_{a1} w)(\gamma_{b0} + \gamma_{b1} w) + \sigma_{u_{ai}, u_{bi}} \text{ and} \quad (8)$$

$$E(c_i' \,| W_i = w) = \gamma_{c'0} + \gamma_{c1'} w, \quad (9)$$

respectively, where w represents age group and γs and $\sigma_{u_{ai}}, u_{bi}$ are estimates from the model above. Evidence for moderated mediation is provided by a joint test of the significance of γ_{a1} and γ_{b1}, implemented using the IndTest macro (Bauer et al., 2006), and extent of mediation is derived as the percentage of the total effect attributable to the indirect effects in each age group. Finally, the robustness of the results was examined by including effects of day of the week (weekdays coded 0, Saturday coded 1) and within-subject centered versions of sleep quality and time of assessment on next-day tiredness and sleep quality and day of the week on sleep duration, including interactions with age group to test for potential moderation. The pattern of results for the associations among alcohol use, sleep duration, and next-day tiredness across age groups was unchanged. As such, the more parsimonious models are reported here.

Results

Descriptive statistics of the alcohol use, sleep duration, and next-day tiredness variables by age group are presented in Table 1. In line with previous research demonstrating less variance in older relative to younger adults in sleep-related variables (Dillon et al., 2015; Wolff et al., 2012), older adults relative to younger adults had lower intraindividual standard deviations (*iSD*s) for both sleep duration (average iSD_{Older} =.68, iSD_{Younger} = 1.27), $t(164)$ = 11.32, $p < .001$, and next-day tiredness (average iSD_{Older} =.68, iSD_{Younger} = 1.10), $t(164) = 9.35$, $p < .001$. These differences thus suggested use of the multilevel model with heterogeneous variances described earlier.

Associations Between Alcohol, Sleep Duration, and Tiredness Across Age Groups

Results from the moderated mediation model examining age-group differences in the within-subject associations among alcohol use, sleep duration, and next-day tiredness are presented in Table 2 and Figure 3. For the younger adults, there were significant associations between alcohol use and sleep duration ($\gamma_{10} = -.12$, $p < .0001$), sleep duration and next-day tiredness ($\gamma_{20} = -.31$, $p < .0001$), and alcohol use and next-day tiredness ($\gamma_{30} = .03$, $p = .004$). The associations were in the expected directions, with greater-than-usual alcohol use associated with shorter-than-usual sleep duration, shorter-than-usual sleep duration associated with more-than-usual next-day tiredness, and greater-than-usual alcohol use associated with greater-than-usual next-day tiredness.

In line with the hypothesized moderated mediation pattern, the within-subject associations between alcohol use and sleep duration, and between alcohol use and next-day tiredness, were moderated by age group (γ_{11} =.08, p = .002, and $\gamma_{31} = -.04$, $p = .04$, respectively). As seen in Figure 3, associations between alcohol use and sleep duration, as well as alcohol use and next-day tiredness, were stronger among younger adults than among older adults. As expected, there was no evidence of age-group differences in the within-subject association between sleep duration and next-day tiredness (γ_{21} =.001, p = .96). As well, residual variances of both next-day tiredness and sleep duration were significantly smaller among older adults than among younger adults ($\alpha_1 = -.87$, $p < .0001$; $\alpha_3 = -.30$, $p < .0001$, respectively).

Age-Group Differences in Mediation by Sleep Duration

Of particular interest were age-group differences in the role of sleep duration as a mediator. Indeed, the indirect effect between

Table 1
Descriptive Statistics for Daily Alcohol Use, Sleep Duration, and Next-Day Tiredness for Younger and Older Age Groups

Variable	Intraindividual means and standard deviations		Intraindividual correlation (range)	
	iM (*SD*)	*iSD* (*SD*)	Alcohol	Sleep
Younger adults (n = 91)				
Alcohol (no. of drinks[a])	.64 (.52)	1.19 (.72)	—	
Sleep (hours)	7.20 (.68)	1.27 (.38)	−.11 (−.53 to .23)	—
Tiredness (0–7 scale)	3.29 (.81)	1.10 (.30)	.07 (−.20 to .46)	−.36 (−.81 to .01)
Older adults (n = 75)				
Alcohol (no. of drinks[a])	.61 (.63)	.61 (.36)	—	
Sleep (hours)	7.06 (.84)	.68 (.27)	−.03 (−.33 to .35)	—
Tiredness (0–7 scale)	2.19 (.93)	.68 (.28)	−.01 (−.26 to .29)	−.30 (−.77 to .09)

Note. *iM* = intraindividual mean; *iSD* = intraindividual standard deviation; *SD* = sample-level standard deviation.
[a] 1 drink = 14 grams alcohol.

Table 2
Moderated Mediation (1–1–1) Model Examining the Associations Among Alcohol Use, Sleep Duration, and Next-Day Tiredness in Older and Younger Adults

Variable	Estimate	*SE*	*p*
Fixed effects			
Alcohol use → sleep duration (γ_{10})	−.12*	.02	<.0001
Sleep duration → next-day tiredness (γ_{20})	−.31*	.02	<.0001
Alcohol use → next-day tiredness (γ_{30})	.03*	.01	.004
Age group × Alcohol use → sleep duration (γ_{11})	.08*	.03	.002
Age group × Sleep duration → next-day tiredness (γ_{21})	.001	.03	.96
Age group × Alcohol use → next-day tiredness (γ_{31})	−.04*	.02	.04
Random effects			
Random slope variance			
AlcoholUse → Sleep duration on ($\sigma^2_{u_{ai}}$)	.01*	.003	<.0001
Sleep duration → Next-Day tiredness ($\sigma^2_{u_{bi}}$)	.03*	.003	<.0001
Alcohol use → Next-Day tiredness ($\sigma^2_{u_{c'i}}$)	.004*	.001	.004
Covariance ($r_{\sigma^2_{u_{ai}}}\ \sigma^2_{u_{bi}}$)	−.003	.003	.32
Covariance ($r_{\sigma^2_{u_{ai}}}\ \sigma^2_{u_{c'i}}$)	.001	.002	.57
Covariance ($r_{\sigma^2_{u_{bi}}}\ \sigma^2_{u_{c'i}}$)	−.004*	.002	.03
Residual variance			
Next-day tiredness (α_{0Y})	1.08*	.02	<.0001
Age group × Next-Day tiredness (α_{1Y})	−.87*	.02	<.0001
Sleep duration (α_{0M})	.44*	.02	<.0001
Age group × Sleep duration (α_{1M})	−.30*	.03	<.0001
Fit indices			
Akaike information criteria		89,446.60	
Bayesian information criteria		89,477.70	

Note. $N_{\text{observations}}$ = 16,598 days nested within 166 persons.
* $p < .05$.

alcohol use and next-day tiredness ($a_i b_i$) was moderated by age group, $\chi^2(2) = 9.48$, $p = .009$. For younger adults, the estimated average indirect effect was .03 ($SE = .01$, $p < .0001$) and the estimated average total effect of alcohol use on next-day tiredness was .07 ($SE = .01$, $p < .0001$). Thus, about 43% of the association between alcohol use and next-day tiredness was mediated through sleep duration in younger adults. For older adults, the estimated average indirect effect was .01 ($SE = .01$, $p = .30$), whereas the estimated average total effect of alcohol use on next-day tiredness was .002 ($SE = .02$, $p = .89$). As such, the age differences emerged in part because there was no significant association between alcohol use and next-day tiredness to be mediated in older adults. Age-group differences in the size of the average total effect of alcohol use on next-day tiredness are represented by the relative sizes of the pie charts in Figure 3, with the proportion of gray indicating the extent of mediation by sleep duration.

Discussion

The present study tested age-group differences in the effects linking alcohol use, sleep duration, and next-day tiredness in day-to-day life. As hypothesized, we observed age-group differences in the association between alcohol use and next-day tiredness. In younger adults, greater-than-usual alcohol use was associated with shorter-than-usual sleep duration, which, in turn, was associated with greater-than-usual next-day tiredness. In older adults, shorter-than-usual sleep duration was also related to greater next-day tiredness, but alcohol use was not associated with sleep duration. Thus, there appears to be a potentially causal link from alcohol use to sleep duration to next-day tiredness for younger adults but not for older adults, even after accommodating differences in variability in sleep duration and tiredness.

Age Differences in the Associations Among Alcohol Use, Sleep Duration, and Tiredness

Older adults are perceived to be at particular risk for detrimental alcohol-related outcomes (Novier, Diaz-Granados, & Matthews, 2015). This perception of older adults' increased vulnerability to the effects of alcohol stems largely from laboratory-based findings that indicate higher blood-alcohol concentrations in the hour following alcohol administration (Gärtner et al., 1996). However, one of the few studies to examine age differences in the next-day effects of alcohol use—employing a cross-sectional, survey design—observed reduced next-day effects of alcohol in older relative to younger adults (Tolstrup et al., 2014), a finding that does not align with laboratory research. This discrepancy between findings from laboratory and survey studies motivated the present examination of age differences in the association between alcohol use and next-day tiredness—outside the tightly controlled laboratory setting, where restrictions on behavior may preclude participants' engagement in real-world, compensatory processes that counteract the effects of alcohol.

We found that greater-than-usual alcohol use was associated with greater-than-usual next-day tiredness in younger but not older adults. Thus, the present study aligns with the survey findings and conflicts with the laboratory findings. By design, this intensive longitudinal study, wherein each participant provided 3-plus months of reports about their daily experiences, complements both the survey and laboratory studies by providing insight into what happens during

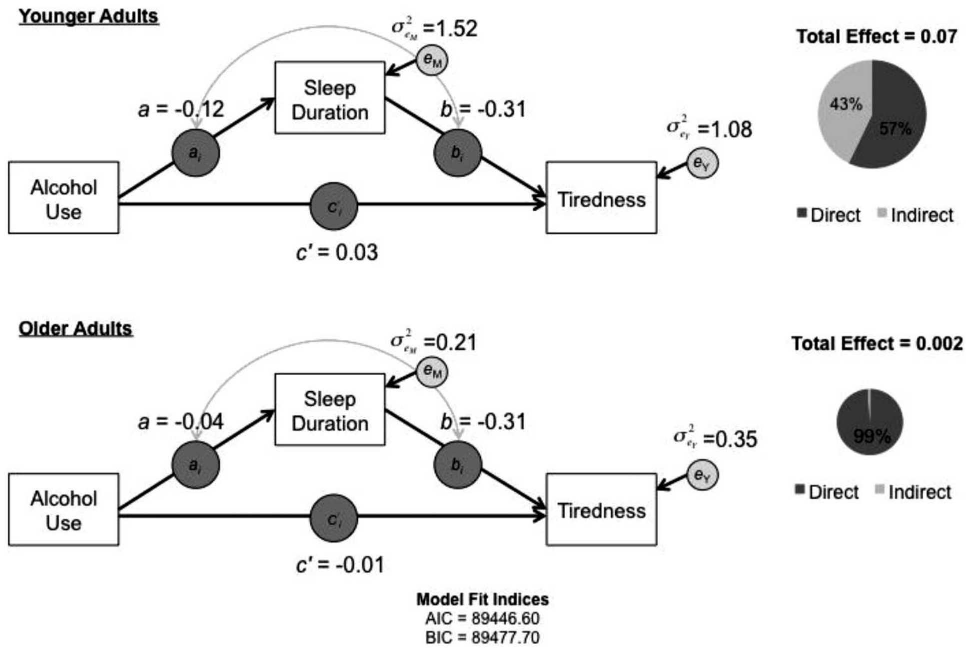

Figure 3. Results of the moderated within-subject mediation model by age group. Age group differences emerged in the alcohol use to sleep duration and alcohol use to tiredness associations, with stronger within-subject associations observed in younger relative to older adults. Pie charts depict age group differences in the total effect of alcohol use on next-day tiredness (size of circle) and the portion of this effect accounted for by sleep duration (proportion of gray). AIC = Akaike information criterion; BIC = Bayesian information criterion.

daily life. That is, this study examined alcohol use in the context of many potential compensatory processes that may counteract alcohol's next-day effects rather than what can happen in strictly controlled laboratory conditions (Mook, 1983) or what individuals report happened. Alcohol use, sleep duration, and tiredness were collected proximal to their occurrence using a measurement approach designed to minimize retrospective biases often associated with questionnaires that ask participants to recall and aggregate information about longer time periods (e.g., previous 30 days; Schwarz, 2007). Coupling the intensive longitudinal data with an analytic framework that appropriately disambiguated within- and between-subjects effects (Bolger & Laurenceau, 2013), we were able to examine age-group differences in the within-subject associations of interest. Although previous work has highlighted that older adults report fewer hangover symptoms than younger adults (Tolstrup et al., 2014), the present study provided more direct evidence that within-subject variations in alcohol use are yoked to changes in next-day tiredness among younger adults but are not yoked among older adults.

A Role for Sleep Duration

The present study considered the role that sleep duration might play as a mediator of the association between alcohol use and next-day tiredness and the age-group differences therein. Sleep has long been known to serve a restorative function, with shorter sleep duration associated with greater next-day tiredness (Moore et al., 2001; Patrick et al., 2016; Zisapel, 2007). We observed no age differences in the association between sleep duration and next-day tiredness, suggesting that the restorative power of sleep pervades at both younger and older ages. In contrast, the association between alcohol use and sleep duration was observed in younger adults but not in older adults. Alcohol use does not generally affect total sleep duration in laboratory studies (MacLean & Cairns, 1982; Yules et al., 1966). However, few constraints are placed on sleep duration following alcohol use in laboratory paradigms. Generally, the laboratory study designs allow participants to get a full night of sleep. In daily life, however, alcohol use and sleep deprivation are often experienced together due to work, family, and other demands (Patrick et al., 2016; Verster, 2008).

The age-group differences in the association between alcohol use and sleep duration reported here are novel and may reflect age differences in maintaining sleep-related routines in the context of alcohol use. Developmental theories highlight age-related differences in daily demands (Charles et al., 2010), as well as priorities and motivations (Carstensen et al., 1999), that have implications for younger and older individuals' ability to maintain routines—including sleep-related routines (Brose et al., 2013). Specific to sleep-related routines in the context of alcohol use, younger adults' alcohol use occurs more frequently in public rather than private places (Grønkjær et al., 2010; Wells et al., 2005), thus rendering it more difficult for them to get to bed. On the other end of the night, younger adults may have more morning duties and constraints, whereas older adults may have greater opportunity to sleep in. This interpretation aligns with the age-group differences in residual variances and with previous research highlighting that older adults have more consistent sleep routines than do younger adults (Dillon et al., 2015; Kramer et al., 1999; Shoji et al., 2015). In sum, alcohol use does not interfere with older adults' sleep duration.

This allows older adults to circumvent the path from alcohol use to next-day tiredness via reduced sleep duration observed in younger adults.

Limitations and Outlook

It is important to consider these findings in light of the study's strengths and limitations. First, collection of data over many days (>100) from many participants (>150) provided for robust examination of between-subjects differences in within-subject processes. However, the cadence of data collection (three-plus times per week) precludes examination of some processes. Supplemental data on the timing of alcohol ingestion throughout the day will provide for more detailed examination of the specific processes through which alcohol influences sleep (Leffingwell et al., 2013). In a related vein, a proposed hypothesis is that age differences in the association between alcohol use and sleep duration are attributed to age differences in the context of alcohol use (public vs. private) and age differences in the tendency to maintain routines. Data were not available to test this hypothesis, and although it is in line with previous research (Burruss et al., 2015; Kramer et al., 1999; Wells et al., 2005), future work will be required to test this possibility.

Collection of polysomnography and actigraphy data alongside self-reported sleep measures will allow greater insight into how age-related changes in specific components of the sleep architecture contribute to differences in how alcohol influences sleep across the life span (Krystal & Edinger, 2008) and will provide more accurate estimates of sleep duration (Lauderdale, Knutson, Yan, Liu, & Rathouz, 2008). This will be important to overcome potential reporting biases that may have been introduced through the use of self-reported sleep duration that varied across time of day, followed alcohol use, and was reported concurrently with tiredness. However, the relatively short period (i.e., hours) between assessment and the events of interest (i.e., sleep duration and alcohol use) in our study, compared to the more distal retrospective reports used elsewhere, likely minimized recall bias (Schwarz, 2007). Reporting biases are also relevant for the alcohol use measure, with some evidence available that younger adults underestimate the amount consumed relative to older adults (Stockwell, Zhao, & Macdonald, 2014).

Second, the nonmandatory nature of the study and its daily assessments suggest consideration of selection effects. For example, the rates of alcohol use in the present study are lower than are those reported in studies that drew random samples of German adults (e.g., Haenle et al., 2006). Given that alcohol use is generally higher on weekends (Kushnir & Cunningham, 2014; Sieri et al., 2002), lack of information on alcohol use on Saturdays (as participants did not come into the laboratory on Sundays and, as such, could not report on alcohol use for Saturday) in the present study may contribute to underassessment. Selection processes may also have functioned during the study. For example, participants might have chosen not to come to the laboratory on days on which they were suffering hangovers. If such self-selection tendencies existed and differed across age groups, the age-comparative results may be biased.

Third, although tiredness is one of the more commonly reported residual effects of alcohol use (Penning et al., 2012), alcohol may also directly or indirectly influence a variety of other symptoms or functions (e.g., loss of appetite, dizziness, stomachache, cognitive speed). Future studies should further consider how the within-subject mediation approaches facilitated by intensive longitudinal designs may provide additional insight into the mechanisms and behaviors affected by alcohol use. In a related vein, although sleep is theorized to mediate the effects of alcohol on a number of next-day effects (e.g., tiredness, concentration problems, reduced appetite), its role as a mediator for other effects is likely more minimal (e.g., thirst, anxiety, coordination problems; see Verster, 2008, for discussion). As such, when considering further next-day effects of alcohol beyond tiredness, considering mediators beyond sleep duration may be more appropriate.

Fourth, any causal interpretation of the effects that combine to the investigated mediation model is based on strong assumptions. For example, the statistical model assumes that all common cause variables influencing both sleep duration and tiredness have been modeled and/or accounted for. Specifically, estimation requires the assumption that the within-subject variations in alcohol use are unrelated to the residuals of sleep duration and tiredness and that these residuals are not correlated with each other. The presence of unmeasured causes beyond alcohol use (e.g., daily health) may bias results. Although these considerations should lead to caution regarding a strict causal interpretation of the mediation model, the suggested mediating role of sleep duration seems to provide a reasonable explanation for the observed pattern of significant age differences in the bivariate associations of the three variables under study.

Finally, given the intensive nature of the study, with the study aimed at participants interested in practicing cognitive tasks for 4–6 days a week for a period of 6 months, generalization to other samples must be done cautiously. Individuals who participate in such studies are special persons who are willing to engage with substantial burden. Adoption of strategies to recruit and retain representative samples (see Mody et al., 2008, for strategies specific to older adults) and use of passive data collection approaches (e.g., sensors integrated into watches, phones, bracelets, and other clothing; (Nusser, Intille, & Maitra, 2006) will increase potential for study of representative samples.

Conclusion

In summary, the current study extends previous examinations of age differences in the next-day effects of alcohol (Tolstrup et al., 2014) by demonstrating age-group differences in the chain linking alcohol use, sleep duration, and next-day tiredness during daily life. Younger adults experienced greater-than-usual tiredness after greater-than-usual alcohol use, an effect that was partially explained by reductions in sleep duration. In contrast, although older adults experienced greater-than-usual tiredness after less sleep, neither tiredness nor sleep was associated with alcohol use. As such, the path from alcohol to tiredness via sleep duration was not present in the older adult group. Viewed next to laboratory studies of the effects of alcohol (Brasser & Spear, 2002; Meier & Seitz, 2008), the results highlight the importance of considering how age-group differences in daily life routines may contribute to differences in how alcohol use affects daily life.

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