

Within-Person Variability in Sensation-Seeking During Daily Life: Positive Associations With Alcohol Use and Self-Defined Risky Behaviors

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Sensation-seeking is the seeking of varied, novel, and intense experiences and the willingness to take risks to engage in these experiences. Sensation-seeking is associated with engagement in risky behaviors but questions remain concerning the role of within-person variability in sensation-seeking. We use data from a 21-day daily diary from 167 participants (mean age = 25.37, $SD = 7.34$) to test within-person associations between sensation-seeking and both alcohol use and self-reported risk-taking. Participants also reported the riskiest behavior they engaged in each day, allowing insight into the perceived risky behaviors that participants take during daily life. Results indicate those days of higher than usual sensation-seeking are more likely to be days on which alcohol is consumed relative to days of no alcohol use. The association between day's sensation-seeking and alcohol use does not extend to the quantity of alcohol consumed. Risk-taking is higher than usual on days of higher than usual sensation-seeking. Using network science tools, we reduce 2,490 self-reports of the day's riskiest behavior to 20 communities reflecting a wide range of risk domains, including social, school, work, and drug use risks. Creating a risk-taking diversity score based on the identified domains of risk behaviors, we find that trait sensation-seeking is positively associated with greater diversity in the types of risks reported. In summary, we observe that sensation-seeking and both alcohol use and other risky behaviors are associated at the within-person level, and provide insight into the types of risks taken during the course of daily life.

Keywords: sensation-seeking, impulsivity, alcohol, risk, daily diary



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Sensation-seeking is defined as the “seeking of varied, novel, complex, and intense sensations and experiences, and the willingness to take physical, social, legal, and financial risks for the sake of such experiences” (Zuckerman, 1994, p. 26). Sensation-seeking as a trait is associated with engagement in behaviors typically deemed risky, including alcohol use (Hittner & Swickert, 2006), cigarette-smoking (Lydon-Staley & Geier, 2018), and high-risk sexual activities (Donohew et al., 2000). Sensation-seeking exhibits intraindividual change—changes construed as developmental, relatively enduring, and that occur over the course of years (Nes-

selroade, 1991). Especially marked declines in sensation-seeking occur over the course of adolescence and into young adulthood (Lynne-Landsman, Graber, Nichols, & Botvin, 2011; Steinberg et al., 2018).

Approaches to personality increasingly consider intraindividual variability in personality traits alongside intraindividual change (Fleeson, 2004; Nesselroade, 1991). Intraindividual variability refers to changes that are relatively short-term, occur more rapidly than those falling under the purview of longitudinal intraindividual change, and that are construed as relatively reversible changes in

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comparison with intraindividual change. When multiple observations of an individual's behavior are collected, the repeated measures data can be modeled as a combination of the individual's trait behavioral tendencies (e.g., using a central tendency measure such as the mean of the time series) and intraindividual variability around these tendencies. Deviations from trait tendencies are thought to reflect short-term changes resulting from person-context transactions (Koffer & Ram, 2015), including changes to accommodate demands of the situation (Fleeson, 2004), the current goals of the individual (Craik, 2000), and basic biological processes, reflecting variations in metabolic rhythms (e.g., neuronal firing, hormonal secretions; Nesselroade & Ford, 1985).

In contrast to considerations of intraindividual change and behavioral tendencies in sensation-seeking over relatively long time horizons, little research examines intraindividual variability in sensation-seeking. Yet, sensation-seeking tendencies may vary within-person at short timescales, from day to day or hour to hour. Variations in sensation-seeking may be associated with short-term changes in positive affect, given that positive affect potentiates the approach motivation and exploration at the heart of sensation-seeking (Fredrickson, 2004). Variations in sensation-seeking may also be associated with the current availability of leisure activities to assuage boredom and the desire for new experiences (Iso-Ahola & Crowley, 1991) and variations in social context that impact motivational states (Chein, Albert, O'Brien, Uckert, & Steinberg, 2011). Further, within-person variation in sensation-seeking may be important for engagement in risky behavior (Lydon-Staley & Bassett, 2018). Indeed, early in the development of the concept of sensation-seeking, state sensation-seeking scales were constructed with the hypothesis that the state preceding behavior would be more predictive of behavior than trait sensation-seeking (Neary, 1975; Zuckerman, 1994). Here we provide an overview of sensation-seeking's purported role in risky behavior before making use of daily reports of sensation-seeking, alcohol use, and risk-taking to test the within-person associations among sensation-seeking and both alcohol use and other self-defined risky behaviors.

A substantial body of work has tested the contribution of sensation-seeking to risky behavior (Coskunpinar, Dir, & Cyders, 2013; Cyders, Flory, Rainer, & Smith, 2009). These studies provide insight into *who* may be most at risk for engaging in risk behaviors. Studies of intraindividual change in sensation-seeking provide insight into *when* during development individuals high in sensation-seeking may be most likely to engage in risk behaviors (Lydon-Staley & Geier, 2018; Quinn & Harden, 2013). Neither type of assessment, however, allows a test of the shorter-time scale within-person processes put forward by perspectives suggesting that risky behavior is preceded by moments of increased sensation-seeking (Lydon-Staley & Bassett, 2018; Zuckerman, 1994). For such a test we must turn to intensive repeated measures. These study designs repeatedly assess individuals as they go about their daily lives. The proximal (in place and time) nature of the assessment provides ecological validity and minimizes retrospective biases introduced in questionnaires asking participants to recall and aggregate information about longer periods of time (e.g., previous 30 days; Schwarz, 2007). For the current aim, intensive repeated measures capture within-person fluctuations in the phenomena of interest and, once appropriately treated to allow both between-person (e.g., "who is most likely to take risks?") and

within-person (e.g., "when is an individual most likely to take risks?") inferences (Curran & Bauer, 2011), can provide insight into intraindividual variability.

The collection of intensive repeated measures is increasingly feasible because of advances in, and the ubiquity of, mobile communication technologies (Pew Research Center, 2017). Few studies have capitalized on this increased feasibility to capture momentary sensation-seeking during the course of daily life. One notable exception included a study that used potential indicators of sensation-seeking ("I have driven recklessly") during the development of a scale designed to assess momentary impulsivity in daily life (Tomko et al., 2014). Because of poor convergent validity between aggregated scores of the momentary impulsivity scale across a 28-day period and scores on a traditional, retrospective self-report sensation-seeking questionnaire, however, the sensation-seeking indicators were not retained in the final scale. In a second relevant study that examined facets of impulsivity during daily life, momentary reports of behaviors related to sensation-seeking (e.g., "Since the last beep, did something risky") were averaged across 7 days. This average score showed positive associations with trait sensation-seeking tendencies as assessed during a laboratory visit (Sperry, Lynam, & Kwapil, 2018), suggesting that these levels of analysis are related between subjects. Within-person associations between sensation-seeking and risky behavior, however, were not examined in these studies, limiting our ability to understand how within person fluctuations in sensation-seeking relate to relevant behaviors. Further, difficulties in validly capturing sensation-seeking during daily life remain. This difficulty, in part, stems from the need for short measurement instruments in intensive repeated measures designs to avoid overburdening participants. Indeed, the use of single-item scales is common in intensive repeated measures studies because of the effort required of participants to respond to many survey prompts over relatively short periods of time (Fisher & To, 2012). Thus, although attention has turned to the capture of sensation-seeking during daily life, much work remains to be done to quickly but validly capture sensation-seeking during daily life and to answer questions concerning the role of within-person variability in sensation-seeking for understanding risky behavior.

The Present Study

We extend understanding of the association between sensation-seeking, alcohol use, and risky behavior in multiple ways. First, we use daily sensation-seeking scales that reliably capture within-person variability in sensation-seeking to test the within-person hypothesis that days of higher than usual sensation-seeking are days of higher than usual alcohol use. Second, by asking participants to rate the extent to which their behavior is risky, we test the within-person hypothesis that days of higher than usual sensation-seeking are days of higher than usual self-reported risk-taking. Third, risk is both fact-laden and value-laden, containing both objective and subjective components, such that there is a need for subjective judgment during risk-taking (Hansson, 2010; Redmill, 2002). By having participants describe their everyday risk behaviors, we gain insight regarding the types of risks that are undertaken during the course of everyday life, moving beyond definitions of risky behaviors that are common in the field (e.g., smoking, illicit drug use, eating unhealthy foods, driving reck-

lessly, and drinking excessively; Reyna & Huettel, 2014) to subjective, participant-elicited definitions.

Finally, although the main focus of the present article is on daily, within-person associations between sensation-seeking and both alcohol use and risk-taking, we leverage the intensive longitudinal data to examine associations between trait sensation-seeking as traditionally assessed with a baseline questionnaire (Hoyle, Stephenson, Palmgreen, Puzles Lorch, & Donohew, 2002; Whiteside & Lynam, 2001) and between-person differences in aggregate estimates of day-to-day risk behavior. Given that sensation-seeking is associated with the seeking of varied, novel, and intense sensations and experiences, we test the hypothesis that trait sensation-seeking is positively associated with a greater diversity in the types of risky behaviors that are practiced in daily life. To do this we couple natural language processing with network science tools to reduce the dimension of many (2,490) idiosyncratic reports of risky behavior into 20 risk domains, providing an illustration of how the complexity of subjective risk as defined by participants themselves may be distilled into meaningful insights using existing analytic methods.

Materials and Methods

We made use of data from the Knowledge Networks Over Time study, an intensive longitudinal study designed to provide insight into day-to-day intraindividual variability across a range of domains of functioning. The variables used in the present study have not been reported on previously (Lydon-Staley, Zurn, & Bassett, 2019). All research was conducted in accordance with the Institutional Review Board (IRB) at our host university. The IRB board at the university declared the study exempt because of the minimal risk the study posed to participants.

Participants

Participants were 167 individuals (136 female, 29 male, 2 other gender) recruited through poster, Facebook, Craigslist, and university research site advertisements in Philadelphia and the surrounding university community. Individuals were eligible if they met four criteria: (a) being between 18 and 65 years of age; (b) having consistent access to a home computer with Internet; (c) being willing to complete 21 consecutive days of surveys; and (d) being willing to visit the research laboratory for 1 hr. Participants were aged between 18.21 and 65.24 years of age ($M = 25.37$, $SD = 7.34$), and identified as African American/Black (8.38%), Asian (23.35%), Hispanic/Latino (4.79%), Multiracial (6.59%), other (5.39%), White (49.10%), and missing information (2.40%). Participants identified as bisexual (7.78%), gay (4.19%), heterosexual (79.04%), lesbian (1.20%), other (5.99%), and missing information (1.80%). Participants reported a yearly family income ranging from under \$20,000 to \$200,000 or more (*Modal income* = \$20,000–\$49,000). Participants' education spanned less than a high school degree (0.60%), high school degree (8.98%), associate's degree or some college but no degree (30.54%), college degree (37.72%), graduate or professional training (20.96%), or missing information (1.20%).

Procedure

Interested participants were directed to a website with study information and a consent form. After confirming that participants met inclusion criteria, they were contacted via telephone with a description of the study and were offered an opportunity to assent or decline participation. If individuals assented, an e-mail was sent with a baseline survey containing demographic questionnaires and additional scales that were not the focus of the present study. After the baseline survey, participants completed a laboratory session. At the laboratory session, participants filled out additional questionnaires, received training in the daily assessment protocol, and were guided through the installation of an app necessary for an Internet browsing study component. Following the laboratory study, a 21-day diary assessment protocol consisting of two components was initiated. The first component was a daily diary composed of survey questionnaires that took approximately 5 min to complete. The second component came immediately after the daily diary component and was a 15 min Internet browsing task that we do not report on in the present article (but see Lydon-Staley, Zhou, Blevins, Zurn, & Bassett, 2019 for more information). Links to the daily assessments were emailed to participants at 6:30 p.m. each evening. Participants were instructed to complete the daily assessments before going to bed but were also informed that links remained open until 10:00 a.m. the next morning. Participants were compensated with Amazon gift cards at each study phase: \$25 after completing the baseline assessment and the laboratory visit. For the daily assessment, completion was incentivized by making participant payment contingent on completion: completion of 3, 4, 5, 6, and 7 surveys each week was compensated with gift cards worth \$10, \$15, \$20, \$25, and \$35, respectively. Continued participation through the daily assessment was further incentivized by using a raffle for which an iPad mini was the prize. Completion of all seven surveys each week resulted in one entry into the raffle drawing.

Measures

The present study made use of participants' reports of demographic and trait characteristics from the baseline surveys and their daily diary reports.

Day's sensation-seeking. Day's sensation-seeking was measured as the average of two items adapted from the Fun-Seeking subscale of the BIS/BAS scales (Carver & White, 1994) and the Excitement-Seeking subscale of the Revised Neuroticism, Extraversion, and Openness Personality Inventory (Costa & McCrae, 1992): "How much of the time today did you crave excitement?" and "How much of the time today did you crave new experiences?" Participants rated how accurately the statement reflected how they behaved today on a scale from 0 = *none of the time* to 10 = *all of the time* in increments of 0.1. The sample-mean of sensation-seeking was 3.12 ($SD = 2.55$, $min = 0$, $max = 10$). Because of the novelty of this scale, we test the reliability and validity of the scale, reporting the approach in the data analysis section and reporting the findings in the results section.

Day's alcohol consumption. Alcohol consumption for the previous day was measured during each daily diary assessment using three items of the form, "Yesterday, how many of the following drinks did you consume?" followed with prompts and definitions of standard servings for "beer" (12 fl. oz.), "wine" (5 fl.

oz.), and “shots of liquor” (1.5 fl. oz.). Responses were given on a 0, 1, 2, 3, 4, 5 + response scale for each beverage category and were summed to obtain the total servings of alcohol consumed the previous day (see Lydon et al., 2016 for previous use of this item). Participants were asked to report on *yesterday’s* alcohol use to ensure that alcohol use that may have occurred after completion of the evening survey was captured. On average, participants consumed 0.68 drinks per day ($SD = 0.71$). On drinking days (27% of all days and with 80.24% of participants having at least one drinking day), participants drank an average of 2.46 drinks ($SD = 1.74$).

Day’s risk-taking. Day’s risk-taking was measured as the average of two items: “Yesterday, I took more or less risks than I normally do” and “Yesterday, my behavior was more or less risky than usual.” Participants provided their responses on a sliding scale from $-50 = \textit{less than usual}$ to $+50 = \textit{more than usual}$ in increments of 1. Participants were instructed during the laboratory session that a score of -50 did not necessarily mean no risks, it meant much less risky behavior or much less frequent risk-taking than usual for them, and that a score of 0 would indicate a day of the same amount of risky behavior that is typical for them. Intra-class correlation (ICC) analyses indicated that the proportion of variance associated with between-person variability in risk-taking was 0.44. The sample-mean of day’s risk-taking was -8.30 ($SD = 20.85$, $\textit{min} = -50$, $\textit{max} = 50$). Participants also reported on their riskiest behavior of the day in an open-ended response to the question “What was the riskiest thing you did Yesterday?” Participants were asked to report on *yesterday’s* riskiest behavior to ensure risky behaviors that may have occurred after completion of the evening survey were captured.

Trait sensation-seeking and impulsivity. Trait sensation-seeking and impulsivity was measured using the Brief Sensation-Seeking Scale (BSSS; Hoyle et al., 2002) and the Urgency, Pre-meditation, Perseverance, and Sensation-Seeking Scale (UPPS; Whiteside & Lynam, 2001) during the baseline survey. The BSSS is an eight-item scale and measures sensation-seeking as comprising four components: thrill and adventure seeking, experience seeking, disinhibition, and boredom susceptibility. Items range from 1 = *disagree strongly* to 5 = *strongly agree*. The mean of all eight items was calculated and had a sample mean of 3.21 ($SD = 0.80$). Internal reliability of the BSSS was excellent ($\alpha = 0.81$).

The UPPS is a 45-item scale made up of four subscales: pre-meditation, urgency, sensation-seeking, and perseverance. Items range from 1 = *agree strongly* to 4 = *disagree strongly* and were reverse coded, when appropriate, such that higher values on an item indicated higher impulsivity. The mean of each subscale was calculated. Participants reported a mean premeditation of 1.87 ($SD = 0.44$), a mean urgency of 2.24 ($SD = 0.57$), a mean sensation-seeking of 2.73 ($SD = 0.61$), and a mean perseverance of 1.80 ($SD = 0.44$). Internal reliability of the subscales was excellent with $\alpha = 0.84, 0.88, 0.87, 0.80$ for premeditation, urgency, sensation-seeking, and perseverance, respectively.

Data Analysis

Data analysis was conducted in four steps. First, we examined the reliability and validity of the sensation-seeking scale used as part of the daily diary. Second, we estimated two separate multi-level models to examine the association between sensation-seeking

and alcohol use and risk-taking, respectively. Third, we analyzed daily reports of risky behaviors to identify the types of risks that participants took during the course of daily life. Fourth, we examined associations between trait sensation-seeking and behavior during the daily diary protocol.

Reliability and validity of day’s sensation-seeking scale. Two items were available for the day’s sensation-seeking scale, allowing us to compute a reliable change score (R_c) designed for intensive longitudinal measures (Cranford et al., 2006). R_c values may range from 0 to 1, with values of 0.70 or above representing a scale with high reliability in terms of capturing within-person change over time. After assessing the reliability of the scale, we then computed an ICC to identify the proportion of between-person and within-person variance in the day’s sensation-seeking scale. The ICC can be thought of as the percentage of total variance in a variable that is attributable to mean differences between persons (Bolger & Laurenceau, 2013). When the ICC is 0, there is no difference in the average levels of a variable across persons. When the ICC is 1, then all the variability in the variable is between persons. Formally, the ICC is computed as:

$$ICC = \frac{Var(b)}{[Var(w) + Var(b)]},$$

where $Var(b)$ is the between-person variance component and $Var(w)$ is the within-person variance component. Larger ICC values indicate a higher proportion of total variance attributable to the between-person level. Small values indicate greater state variability, and larger differences in sensation-seeking within persons across time. ICC values observed in previous daily diary studies for related constructs include values in the range 0.38–0.48 for positive affect (Merz & Roesch, 2011) and approximately 0.41 for urgency (Wright & Simms, 2016).

Although the field lacks a gold standard for assessing the validity of daily scales, the convergent validity of the day’s sensation-seeking measure can be examined by comparing the average day’s sensation-seeking score across the 21 days with existing trait measures of sensation-seeking. No guidelines exist for determining what correlation would indicate satisfactory validity. Based on the development of a previously published momentary scale of a related construct (impulsivity; Tomko et al., 2014), we chose a threshold of $r = 0.30$ as a moderate correlation (Cohen, 1988) indicative of satisfactory validity. Further, we estimated the correlation between the average day’s sensation-seeking scale and three impulsivity subscales to provide evidence for discriminant validity.

Associations between sensation-seeking and alcohol use. We tested the extent to which sensation-seeking was associated with alcohol use. A multilevel model framework (Snijders & Bosker, 2012) was adopted to accommodate the nested nature of the intensive repeated measures data (21 days nested within 167 persons). To allow an examination of both within-person and between-person associations between sensation-seeking and alcohol use, sensation-seeking was parameterized to separate within-person and between-person associations by creating time-invariant (between-person) and time-varying (within-person) versions of the sensation-seeking variable (see Bolger & Laurenceau, 2013). We calculated the time-invariant, between-person variable for *usual sensation-seeking* as the grand-mean centered individual mean score of sensation-seeking across all days in the daily diary study.

Participants with positive values of *usual sensation-seeking* had higher than usual levels of sensation-seeking throughout the study compared with other participants in the sample. Participants with negative values of *usual sensation-seeking* had lower levels of sensation-seeking compared with other participants in the sample. We calculated a time-varying, *day's sensation-seeking* variable as deviations from these between-person means. Thus, zero on *day's sensation-seeking* indicated a day of usual levels of sensation-seeking, negative values indicated days of less than usual levels of sensation-seeking, and positive values indicated days of more than usual levels of sensation-seeking for each individual. The alcohol use variable was shifted forward by 1 day (as the question was phrased to measure previous day's alcohol) such that *day's sensation-seeking* represented sensation-seeking on a concurrent day to the reports of alcohol use.

After data preparation, we fit a multilevel hurdle model (Atkins, Baldwin, Zheng, Gallop, & Neighbors, 2013) using *glmmTMB* in R, specifying a truncated Poisson function (Brooks et al., 2017). Count data such as alcohol use data (i.e., number of drinks consumed) are often positively skewed and include many observations at zero. Indeed, this is the case with the current data (online supplemental materials Figure S1). These data violate the distributional assumptions of linear mixed models. Hurdle models include a logistic regression to model the zeroes in the data as well as a count regression (in this case Poisson) to model the counts. All the zeroes (nonalcohol use days) are modeled with the logistic regression and nonzero-counts (alcohol use days) are modeled by a truncated Poisson (i.e., truncated as it does not contain zero). We regressed alcohol use on *day's sensation-seeking*, *usual sensation-seeking*, *weekend* (dummy coded such that Friday, Saturday, and Sunday were indicated by 1), *day of study* to account for time as a third variable (Bolger & Laurenceau, 2013), and we included *age* and *gender* as covariates. We specified random intercepts and random slopes for *day's sensation-seeking* and *day of study* at both the zero and count levels of the model.

Associations between sensation-seeking and risk-taking. We tested the extent to which sensation-seeking was associated with risk-taking using a linear multilevel model. The risk-taking variable was shifted forward by 1 day (as the question was phrased to measure previous day's risk-taking) such that *day's sensation-seeking* represented sensation-seeking on a concurrent day to the reports of risk-taking. The risk-taking variable was designed to provide insight into within-person deviations but not between-person information (i.e., the scale was centered at 0 for a day of usual risk-taking by design; see Fosco & Lydon-Staley, 2019 for a similar approach). However, the mean of the risk-taking variable across the 21 days was significantly lower than 0 (see significant intercept term in multilevel model in the section entitled "Day's Sensation-Seeking Is Positively Associated With Day's Risk-Taking"), suggesting that, for some participants, their risk-taking was lower than usual for them across the 21 day study period or that some participants show more bias in their reporting of their "usual" risk-taking. As such, in addition to including time-varying predictors, and regressing risk-taking on *day's sensation-seeking*, *weekend*, and *day of study*, we included *usual sensation-seeking*, *age*, and *gender* as between-person predictors to examine between-person differences in risk-taking. We specified a random intercept and random slopes for *day's sensation-seeking* and *day of study*.

The model was estimated using *nlme* in R (Pinheiro, Bates, DebRoy, Sarkar, & R Core Team, 2018).

Risk-taking in daily life. To provide insight into the types of risks participants were taking during the course of their daily lives, we used natural language processing methods coupled with network analysis to provide a meaningful description of the vast amount of risk-taking entries ($n = 3,141$) collected during the daily diary (see also Ji, Machiraju, Ritter, & Yen, 2015 for an example of the use of this method as a data reduction technique). Days on which no risks were reported (e.g., "I didn't do anything that I would consider risky") were removed, leaving 2,490 entries. We tokenized the text of each entry using *tidytext* (Silge & Robinson, 2016), segmenting the text of each entry into separate words. We removed stop words that are commonly used in the English language (e.g., "and," "the," and "of") and that were not of interest for quantifying the similarity among entries using a list of words provided through *tidytext* based on three lexicons of "onix," "SMART," and "snowball." We then removed nonalphabetical characters from the text. We reduced words to their word stem form. Taking all entries, we computed term frequency-inverse document frequency (tf-idf) values for each term within each document. After calculating the tf-idf for each entry, we quantified the similarity between all pairs of text entries by computing the cosine similarity. The cosine similarity is a quantification of entry similarity ranging from 0 to 1, with higher values indicating greater similarity.

We then performed community detection in MATLAB using the brain connectivity toolbox (Rubinov & Sporns, 2010) on the $2,490 \times 2,490$ undirected adjacency matrix of the cosine similarity between all possible pairs of risk entries. The aim of the community detection was to assign each text entry to a community within which the nature of the risks described was similar. The algorithm, a Louvain-like locally greedy method, has been demonstrated to provide high quality results (Blondel, Guillaume, Lambiotte, & Lefebvre, 2008). The algorithm was applied with a default structural resolution parameter of 1. As the heuristic is nondeterministic, the algorithm was iterated 100 times. The procedure resulted in 100 vectors indicating the community assignment of each of the 2,490 reported risk behaviors for each of the 100 algorithm iterations. Across these 100 vectors, we chose the representative partition of the risk behaviors into communities in a two-step process. First, we calculated the similarity between partitions obtained from the different algorithm iterations using the z -score of the Rand coefficient (Traud, Kelsic, Mucha, & Porter, 2011). For each pair of partitions α and β , we calculated the Rand z -score in terms of the number of pairs of nodes in the network M , the number of pairs M_α that are in the same community in partition α , the number of pairs M_β that are in the same community in partition β , and the number of pairs of nodes $W_{\alpha\beta}$ that have the same community assignment in partition α and partition β :

$$z_{\alpha\beta} = \frac{1}{\sigma_{W_{\alpha\beta}}} W_{\alpha\beta} - \frac{M_\alpha M_\beta}{M},$$

where $\sigma_{W_{\alpha\beta}}$ is the standard deviation of $W_{\alpha\beta}$ (see Doron, Bassett, & Gazzaniga, 2012). We then determined the partition that was the most similar to all other partitions by identifying the partition with the largest average z -score and took that forward for the remainder of the analyses. Once text entries had been assigned to communi-

ties, we calculated the most frequent words within communities to identify the most common risks captured by each community, and we gave titles to each community that captured the prototypical risks reported in each community. This procedure resulted in 13 communities reflecting domains of risk as well as seven additional idiosyncratic risks that were not assigned to any community. We make use of the community assignments in the creation of a risk-taking diversity score below.

To complement the data-driven analysis of risky behaviors, four researchers independently coded each of the 2,490 self-reports as either “not threatening to safety, health, or wellbeing” or “threatening to safety, health, or wellbeing.” Taking a conservative approach, we created a binary “nonthreatening” (0) or “threatening” (1) score for each risk behavior, coding a 1 for behaviors that were unanimously viewed as appearing threatening across all coders. We next used regression to examine the extent to which between-person differences in sensation-seeking, age, and gender, and the number of risks reported were associated with the proportion of threatening risk behaviors. Because of the nature of the dependent variables (proportions bounded by 0 and 1) we made use of a generalized linear model with a logit link and robust standard errors.

Sensation-seeking and risk-taking diversity. To examine the association between sensation-seeking and the diversity of risk behaviors reported during the course of daily life, we created a risk-taking diversity index. For each individual, we computed the frequency with which their self-reported riskiest behavior of the day fell into each risk domain identified in the community detection step above (see Risk-taking in daily life section). We then calculated Shannon’s diversity index:

$$RiskTaking\ Diversity_i = H_i = -\sum_{j=1}^m p_{ij} \ln(p_{ij}),$$

where m is the number of risk communities and p_{ij} is the proportion of participant i ’s risk behaviors that were of each discrete risk type, $j = 1$ to m . Scores can range from 0 to $\ln(m)$, with higher scores indicating greater risk-taking diversity. Then, we ran regression analyses in which this risk-taking diversity index was the dependent variable and was predicted by trait sensation-seeking,

while controlling for both age and gender and the number of daily diary days completed.

Results

To examine daily fluctuations in sensation-seeking, impulsivity, and their associations with alcohol use and risk-taking, we use 21-day daily diary data. Out of a possible total of 3,507 daily diary days (21 days \times 167 participants), 3,141 (89.56%) were available. The number of daily diary days completed by participant ranged from 11 to 21 ($M = 18.81$, $SD = 2.75$). We provide descriptive statistics and zero-order correlations of the variables used in the analyses in Table 1.

Reliability and Validity of the Day’s Sensation-Seeking Scale

The sensation-seeking scale exhibits reliable within-person change ($R_c = 0.85$; see Table S1 for variance partitioning of the sensation-seeking scale). ICC analyses indicate that the sensation-seeking scale is composed of approximately equal parts within-person and between-person variance ($ICC = 0.51$). The mean of the day’s sensation-seeking score shows positive and moderate correlations with two trait measures of sensation-seeking, the Brief Sensation-Seeking Scale, $r = 0.40$, $p < .001$ and the UPPS sensation-seeking subscale, $r = 0.34$, $p < .001$, providing evidence for the scale’s convergent validity. Notably, correlations between the day’s sensation-seeking scale and the premeditation, perseveration, and urgency subscales of the UPPS are not significant (all p values greater than 0.05; Table 1), providing evidence for discriminant validity of the scale.

Day’s Sensation-Seeking Is Positively Associated With Day’s Alcohol Use

We ran a multilevel hurdle model to examine whether day’s sensation-seeking was associated with day’s alcohol use (see Table 2). The zero-inflation submodel of the hurdle model estimates the probability of an extra zero (no alcohol use) such

Table 1
Correlations and Descriptive Statistics of Key Study Variables

Variables	1	2	3	4	5	6	7	8	9
1. Sensation-seeking ^a	—								
2. Alcohol use ^a	0.16*	—							
3. Risk-taking ^a	0.09	0.12	—						
4. BSSS	0.40***	0.26***	0.01	—					
5. UPPS-SS	0.34***	0.12	−0.13	0.72***	—				
6. UPPS-PREM	0.08	0.11	−0.02	0.51***	0.36***	—			
7. UPPS-PERS	−0.03	0.02	0.02	0.14	−0.01	0.37***	—		
8. UPPS-URGE	0.05	0.10	0.07	0.28***	0.10	0.48***	0.48***	—	
9. Age	−0.18*	0.07	−0.45***	−0.07	−0.03	0.14	0.00	0.00	—
Mean	3.15	0.68	−8.44	3.21	2.73	1.87	1.80	2.24	25.19
Standard deviation	1.91	0.71	14.43	0.80	0.61	0.44	0.44	0.57	6.89

Note. BSSS = Brief Sensation-Seeking Scale; UPPS = Urgency, Premeditation, Perseverance, and Sensation-seeking Scale; SS = sensation-seeking; PREM = premeditation; PERS = perseverance; URGE = urgency.

^a Intraindividual mean of the daily diary time series; $N = 167$.

* $p < .05$. *** $p < .001$.

Table 2
Results of the Multilevel Hurdle Model Examining Associations With Alcohol Use

Effect	Estimate	Standard error	p-value
Conditional submodel			
Fixed effects			
Intercept	0.37***	0.08	<.001
Day's sensation-seeking	0.02	0.03	.50
Weekend	0.18*	0.07	.01
Day of study	-0.003	0.01	.74
Usual sensation-seeking	0.05	0.04	.17
Age	-0.02*	0.01	.04
Gender male	0.33	0.18	.06
Gender other	-1.16	1.05	.27
Random effects			
	Estimate	Standard deviation	
Intercept	0.36	0.60	
Day's sensation-seeking	0.01	0.11	
Day of study	0.001	0.03	
Zero-inflation submodel			
Fixed effects			
Intercept	1.71***	0.17	<.001
Day's sensation-seeking	-0.08*	0.04	.04
Weekend	-0.42***	0.11	<.001
Day of study	-0.0003	0.01	.98
Usual sensation-seeking	-0.08	0.08	.31
Age	-0.05*	0.02	.01
Gender male	0.003	0.37	.99
Gender other	0.46	1.34	.73
Random effects			
	Estimate	Standard deviation	
Intercept	2.57	1.60	
Day's sensation-seeking	0.01	0.09	
Day of study	0.003	0.06	

Note. $N = 2,737$ days nested within 167 participants.
* $p < .05$. *** $p < .001$.

that a positive contrast indicates a higher chance of no alcohol use. Days of higher than usual sensation-seeking are more likely to be days on which alcohol is used ($b = -0.08, p = .04$) and weekend days are more likely to be alcohol use days relative to weekdays ($b = -0.42, p < .001$). There is no association between day in the study and the probability of no alcohol use days ($b = -0.0003, p = .98$). At the between-person level, there is no association between usual sensation-seeking or gender and the probability of more or less alcohol use days (all p values >0.05). Young participants are more likely to have more alcohol use days relative to older participants ($b = -0.05, p = .01$).

The conditional submodel of the hurdle model estimates the positive count process, providing insight into variables that increase or decrease the likelihood of consuming more alcohol on alcohol use days. Day's sensation-seeking is not associated with amount of alcohol consumed ($b = 0.02, p = .50$). Greater amounts of alcohol are consumed on weekend drinking days relative to weekday drinking days ($b = 0.18, p = .01$). Day of study is not associated with alcohol consumption ($b = -0.0003, p = .74$). At the between-person level, no

association between usual sensation-seeking, gender, and alcohol use emerged (all p values >0.05). Older participants consumed less alcohol relative to young participants on alcohol use days ($b = -0.02, p = .04$).

Day's Sensation-Seeking Is Positively Associated With Day's Risk-Taking

The risk-taking scale exhibited reliable within-person change $R_c = 0.88$. We ran multilevel models to examine whether day's sensation-seeking was associated with day's risk-taking (see Table 3). Days of higher than usual sensation-seeking are also days of higher than usual risk-taking ($b = 0.61, p = .02$). Risk-taking is higher than usual on weekends relative to weekdays ($b = 1.50, p = .01$) and increases over the course of the study ($b = 0.14, p = .03$). Usual sensation-seeking and gender are not associated with risk-taking across the study (all p values >0.05). Older participants exhibited lower than usual risk-taking during the daily diary relative to younger participants ($b = -0.79, p < .001$).

Risks in Daily Life

Participants report riskier behavior on days of higher than usual sensation-seeking ($b = 0.61, p = .02$; Table 3). To provide insight on the types of risks that participants engaged in during the daily diary protocol, we created a visualization of the network resulting from the cosine similarity analysis on the self-reported riskiest behaviors of the day (see Figure 1). Nodes represent individual reports and edges represent the cosine similarity between reports. Twenty communities were identified by community detection. Seven communities contained only one risky behavior; these were highly idiosyncratic risk behaviors that occurred only once and included "dissected fetal pig" and "tanned." The community allegiance of the nodes of the other 13 communities is indicated by color. A list of the top five most frequent words associated with self-reports within each community is shown. In the online supplemental materials, we thoroughly describe the prototypical behaviors associated with each community. Here, we

Table 3
Results of the Multilevel Model Examining Associations With Day's Self-Reported Risk-Taking

Effect	Estimate	Standard error	p-value
Fixed effects			
Intercept	-7.01*	3.27	.03
Day's sensation-seeking	0.61*	0.26	.02
Weekend	1.50*	0.58	.01
Day of study	0.14*	0.06	.03
Usual sensation-seeking	-0.02	0.55	.97
Age	-0.79***	0.14	<.001
Gender male	-3.19	3.32	.34
Gender other	1.59	3.58	.66
Confidence interval			
Random effects			
Intercept	12.96	11.50-14.61	
Day's sensation-seeking	2.29	1.85-2.83	
Day of study	0.49	0.35-0.68	

Note. $N = 2,737$ days nested within 167 participants.
* $p < .05$. *** $p < .001$.

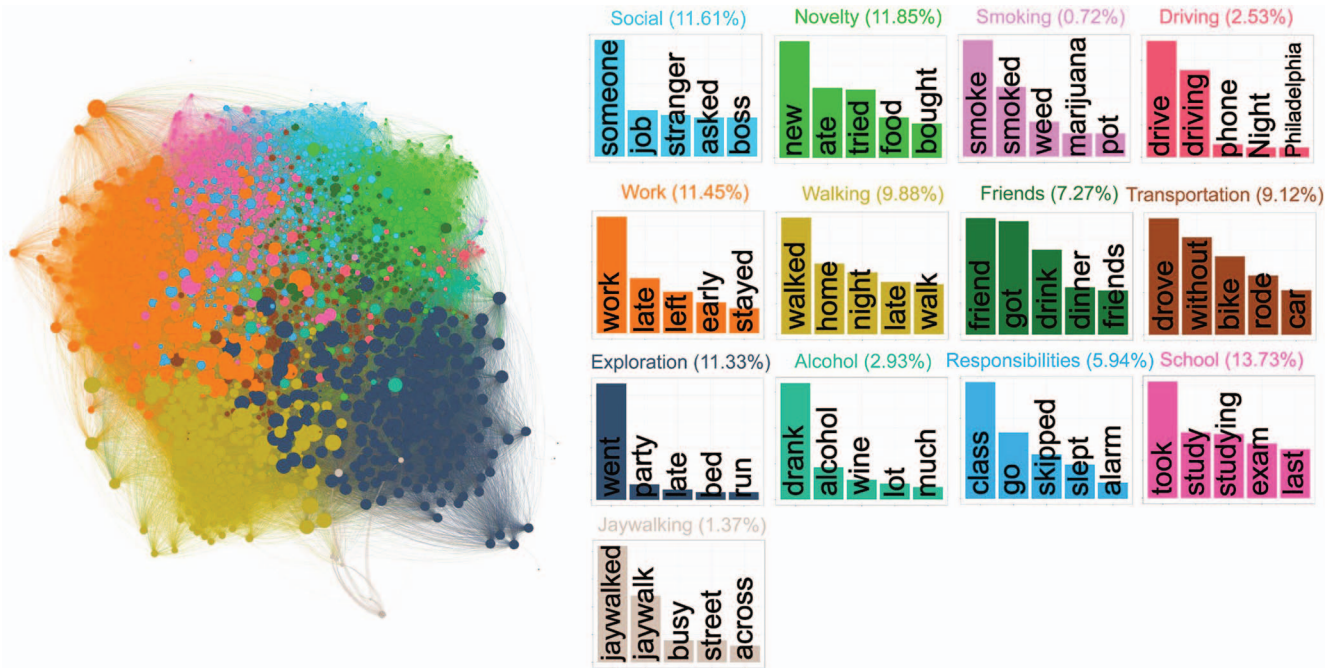


Figure 1. Semantic network of riskiest behaviors of the day. Each node represents one of 2,490 self-reports of the riskiest action that participants performed on the previous day. Edges reflect cosine similarity based on term frequency inverse document frequency between reports. Nodes were placed according to a force directed layout (Jacomy, Venturini, Heymann, & Bastian, 2014) and are colored to illustrate community assignment. The top five most frequent words associated with each community are shown in bar plots along with the percentage of reports (out of the 2,490 reports) contained within the community. Notably, the alcohol use community and the smoking community (comprising other substance use) make up a small percentage of the perceived riskiest behaviors of the day. See the online article for the color version of this figure.

focus on insights focal to our interests in alcohol use and sensation-seeking.

First, two communities of risk behaviors were identified that were made up of risk-taking specific to substance use. An *alcohol risks* community made up a small percentage (2.93%) of the riskiest behavior of the day reports with entries such as: “drank too much,” “Drank champagne while sick,” “drank more wine than I typically do,” and “drank a beer outside on the street.” Additionally, the smallest community (0.72%) was comprised of *smoking risks* and containing reports such as: “smoked weed,” “smoke hookah,” and “smoke.”

Examining the results of the manual coding of risk behaviors, we find that the average pairwise percent agreement among coders was 91.18%. The Fleiss’ kappa (Fleiss, 1971) was 0.75, indicating substantial agreement among coders. Out of 2,490 reported risks, 271 (14.90%) were unanimously coded as risks that are threatening to safety, health, or wellbeing. The percent of risk behaviors coded as threatening within each category identified via community detection is shown in [online supplemental materials Table S2](#). Substance use risk categories, including smoking risks (94.44%) and alcohol use risks (56.16%) were among the risk categories with the greatest percent of threatening risks.

To further understand the finding that alcohol use, and substance use more broadly, was rarely reported as the riskiest behavior of each day but was often coded as threatening to safety, health, or wellbeing

by researchers, we examined the day-level association between alcohol use and risky behavior in a multilevel model. We find that there is no linear association between the quantity of day’s alcohol use and day’s risk-taking ($b = -0.35, p = .18$; [online supplemental materials Table S3](#)), though there is evidence that days of alcohol use relative to no alcohol use were days of greater than usual risk-taking ($b = 5.66, p < .001$; [online supplemental materials Table S4](#)).

Trait Sensation-Seeking and Diversity and Threat of Risk Behaviors

Using the 13 communities of risk (see [Figure 1](#)), as well as an additional “Other risk” category in which the seven risk communities consisting of only one risk were combined, we calculated Shannon’s diversity index as a measure of risk-taking diversity. Regression analyses reveal that the BSSS and the sensation-seeking subscale of the UPPS are positively associated with the risk-taking diversity score controlling for age, gender, and the number of days of the daily diary protocol completed (see [Table 4](#)).

Using the manual coding of risks as threatening or nonthreatening to safety, health, or wellbeing, we calculated the proportion of threatening risks for each participant. The proportion of threatening risks variable is positively correlated with risk-taking diversity ($r_s = 0.25, p = .001$). Regression analysis revealed some evidence that participants high in sensation-seeking reported a greater proportion of threat-

Table 4
Results of the Multiple Regression Analyses Examining Associations Between the Brief Sensation-Seeking Scale and Risk-Taking Diversity (Top) and the UPPS Sensation-Seeking Subscale and Risk-Taking Diversity (Below)

Variable	Estimate	Standard error	p-value
Risk-taking diversity and Brief Sensation-Seeking Scale			
Intercept	0.29	0.32	.38
BSSS	0.17***	0.05	<.001
Age	-0.02**	0.01	.001
Gender male	-0.13	0.10	.19
Gender other	0.31	0.35	.38
Number of days	0.04**	0.01	.004
R ²	0.17		
F	6.47***		
Risk-taking diversity and UPPS sensation-seeking subscale			
Intercept	0.38	0.34	.26
UPPS-SS	0.18**	0.06	.006
Age	-0.02***	0.01	<.001
Gender male	-0.14	0.10	.17
Gender other	0.32	0.36	.37
Number of days	0.04*	0.01	.01
R ²	0.14		
F	5.43***		

Note. BSSS = Brief Sensation-Seeking Scale; UPPS = Urgency, Pre-emption, Perseverance, and Sensation-Seeking Scale; SS = sensation-seeking. $N = 167$. Age was sample-mean centered. Gender was a factor variable with female as the reference category.

* $p < .05$. ** $p < .01$. *** $p < .001$.

ening risks, with a positive association between the BSSS and proportion of threatening risks ($b = 0.29, p = .04$; [online supplemental materials Table S5](#)). However, we observe no positive association between the sensation-seeking subscale of the UPPS and proportion of threatening risks ($b = 0.16, p = .37$; [online supplemental materials Table S5](#)). Instead, the most robust between-person variable associated with proportion of threatening risks was male gender, with males reporting a greater proportion of threatening risks relative to females ($b = 0.62, p = .03$; [online supplemental materials Table S5](#)).

Robustness and Additional Analyses

Additional analyses confirm that results for alcohol use are robust to the inclusion of participants exhibiting no alcohol use throughout the 21 days and who could not provide insight into the within-person association between sensation-seeking and alcohol use (see Lydon-Staley, Ram, Brose, & Schmiedek, 2017; Ram, Brinberg, Pincus, & Conroy, 2017; [online supplemental materials Table S6](#)). Results for alcohol use and risk-taking are also robust to the inclusion of previous day's sensation-seeking as well as controlling for previous day's alcohol use ([online supplemental materials Table S7](#)) and previous day's risk-taking ([online supplemental materials Table S8](#)).

Discussion

Sensation-seeking is associated with engagement in risky behaviors and exhibits marked intraindividual change over development. Despite theorized roles for short-term, within-person fluctuations in sensation-seeking in risk-taking and the necessity of

considering both intraindividual change and intraindividual variability to thoroughly characterize individuals, little work has considered intraindividual variability in sensation-seeking. We measured naturalistic day-to-day fluctuations in sensation-seeking over the course of 21 days and tested *within-person* associations between sensation-seeking and both alcohol use and self-defined risky behavior. Our measure of sensation-seeking was capable of reliably measuring within-person change ($R_c = 0.85$) and exhibited within-person variance, with ICCs suggesting approximately 51% of the variance in sensation-seeking across 21 days is associated with between-person, as opposed to within-person, variance. For comparison, other studies show that between 38% and 48% of the variance in positive affect (Merz & Roesch, 2011) and 41% of the variance in urgency (Wright & Simms, 2016) is associated with between-person variance. The scale exhibited convergent validity in the form of moderate, positive correlations with two trait sensation-seeking scales. Notably, the magnitude of these correlations is in line with estimates of convergent validity between momentary and trait scales for related constructs (impulsivity) with double the number of momentary items (Tomko et al., 2014). In addition, evidence for discriminant validity emerged such that the average day's sensation-seeking score was not correlated with impulsivity subscales of the UPPS. Thus, the measure of day's sensation-seeking is short, reliably captures within-person fluctuations, exhibits convergent validity with two trait sensation-seeking scales, and exhibits divergent validity with measures of impulsivity.

Capturing fluctuations in sensation-seeking allowed us to disaggregate within-person and between-person variance in sensation-seeking and to test within-person theories of the role of sensation-seeking in risk behaviors (Lydon-Staley & Bassett, 2018). Consistent with the hypothesized importance of state sensation-seeking in promoting risky behavior, days of higher than usual sensation-seeking were also more likely to be days of alcohol use relative to days of no alcohol use. Day's sensation-seeking was not associated with the amount of alcohol consumed on drinking days. There was no association between alcohol use and sensation-seeking at the between-person level after controlling for age (although see [online supplemental materials Table S9](#) for a model without age showing a positive association between trait sensation-seeking and quantity of alcohol use). The distinct associations between sensation-seeking and alcohol use at the between-person and within-person levels highlight the importance of disentangling within-person and between-person variance to make within-person inferences. Findings observed at the between-person level may not generalize to the within-person level (Hamaker, 2012). Also consistent with our hypotheses was the finding that days of higher than usual sensation-seeking were also days of higher than usual engagement in self-defined risky behavior.

By having participants report on the riskiest behavior they engaged in each day, we additionally provide novel insight into the risks that individuals undertake during the course of daily life. Only a small portion (2.93%) of self-reported risks concerned alcohol use risks. Other substance use, in particular smoking, also emerged as a risk domain and, similar to alcohol use, concerned a small portion (0.72%) of reported risks. These results highlight that a focus on substance use when considering risk behavior fails to capture the majority of behaviors participants perceive to be risky in their daily lives and illustrates the importance of consid-

ering the subjective nature of risk (Hansson, 2010; Redmill, 2002) alongside investigator-defined constructs of risk.

Notably, although alcohol use was rarely considered the riskiest behavior engaged in during the study, positive within-person associations between alcohol use and risk-taking suggest that alcohol use may be a precursor to risky behaviors. These findings are in line with existing between-person findings illustrating that individuals who consume greater amounts of alcohol engage in more risk behaviors and experience greater risk-related injuries (O'Neill, Martin, Birch, Oldam, & Newbury-Birch, 2015). Notably, our study extends beyond these prior studies by identifying consistent effects at the within-person level. The associations between day's sensation-seeking, day's alcohol use, and day's risk behavior will benefit from further interrogation using fine-grained temporal data collected within-day to examine the extent to which the association between day's sensation-seeking and day's risk-taking is mediated through day's alcohol use.

Although the main focus of the study was on the within-person associations between sensation-seeking and both alcohol use and risk-taking, we collected data on trait sensation-seeking. This experimental design allowed us to examine how trait sensation-seeking was associated with behavior during the course of daily life. As hypothesized, participants high in trait sensation-seeking reported greater diversity in the categories of risk behaviors that they engaged in during the daily diary period. This diversity of risk engagement is in line with the emphasis on the tendency to seek out novel experiences at the core of conceptualizations of trait sensation-seeking. These findings add to perspectives that consider the positive side of sensation-seeking (Hansen & Breivik, 2001; Yoneda, Ames, & Leadbeater, 2019) whereby the increased tendency of sensation-seekers to take risks to experience novel and exciting experiences leads to potentially detrimental outcomes (e.g., addiction) but also potential benefits (e.g., the accrual of new skills). More diverse risk engagement does not necessarily mean engagement in riskier behavior—it is an indication of the extent to which an individual's self-reported riskiest behavior of the day was spread across the categories of risk identified in the network analysis of risk behavior self-reports. Indeed, manually coding the self-reported risks revealed mixed evidence for an association between sensation-seeking and engagement in a greater proportion of risks that may threaten safety, health, and well-being.

Limitations and Future Outlook

Our use of daily diaries allowed us to capture naturally occurring fluctuations in sensation-seeking, alcohol use, and risky behavior during life as it is lived (Bolger, Davis, & Rafaeli, 2003). However, the daily diary data are limited in their ability to evaluate temporal precedence. Future work, drawing on multiple occasions each day, will provide greater possibilities to examine putative causal associations. Additionally, reporting on previous day's alcohol use and risk behavior in the evening lengthened the period between the time of the behaviors and its recall. Our choice of using evening rather than morning surveys reflected the length of the daily diary assessment (approximately 20 min in total because of a 15-min computer task that is not reported on in the present article and that followed the daily diary surveys).

Our measure of sensation-seeking is based on two items and may not capture the full breadth of the construct. Indeed,

sensation-seeking is sometimes broken down into facets that include thrill and adventure seeking, experience seeking, disinhibition, and boredom susceptibility. Longer day sensation-seeking scales in daily diary designs will allow the capture of these subcomponents of sensation-seeking and an examination of the factor structure of sensation-seeking at the within-person level (Brose & Ram, 2012). Despite these limitations, the day's sensation-seeking scale is capable of reliably capturing within-person change and shows satisfactory convergent and discriminant validity with two trait sensation-seeking scales while being short enough (two-items) to be readily accommodated in experience-sampling designs.

The network approach to self-reported risks leverages best-practices in natural language processing and graph theory to render the large number of self-reports into interpretable categories of risk. The results should be considered exploratory and may rely on the specific similarity indices and clustering approach used in constructing the semantic network. Further, the analysis ignores the clustered nature of the data (with multiple self-reports nested within an individual). As such, the results are sample-level results and may be more reflective of individuals providing more data than others, with the average number of risk descriptions contributed by participants equal to 14.91 ($SD = 6.26$).

Conclusions

We extend previous examinations of the association among sensation-seeking and risk behaviors by measuring naturalistic fluctuations in sensation-seeking during the course of daily life and demonstrating that days of higher than usual sensation-seeking are also more likely to be days of alcohol use than no alcohol use and also days of riskier behavior than usual. We provide a detailed examination of the types of risks that are taken during everyday life and find that risk-taking is greater on days of alcohol use relative to days of no alcohol use. The findings highlight the importance of considering short-term dynamics in sensation-seeking, alcohol use, and the subjective nature of risk to understand risk behaviors during the course of daily life.

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