



Review

Ecological momentary assessment studies of comorbid PTSD and alcohol use: A narrative review

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ABSTRACT

Introduction: PTSD and harmful alcohol use, including alcohol use disorder (AUD), frequently co-occur. Recent research has used ecological momentary assessment (EMA) to examine the associations between PTSD symptoms and alcohol-related variables, such as craving for alcohol, alcohol use, and the presence of alcohol-related problems. The overall purpose of this narrative review is to summarize this emerging literature.

Methods: Inclusion criteria for studies were: 1) Use of ecological momentary assessment as the method for gathering data on alcohol use and/or craving in populations with both problematic alcohol use and PTSD, and the inclusion of an assessment of both PTSD symptoms and at least one alcohol use variable during EMA; and 2) At screening, participants were required to meet study criteria for a) elevated PTSD symptoms or trauma exposure, and b) alcohol use.

Results: The pertinent extant literature is reviewed in terms of four underlying themes: Methodological considerations of EMA research in a population with PTSD symptoms and harmful alcohol use; Associations between PTSD symptoms and alcohol use variable/s; Moderators of PTSD-alcohol use associations; Mediators of PTSD-alcohol use associations.

Conclusions: Collectively, studies provide support for the self-medication hypothesis. Several variables were found to moderate association between PTSD symptoms and alcohol-related variables. EMA data may ultimately be useful in identifying when individuals are at risk for harm due to increased symptoms or alcohol misuse and may inform treatment approaches administered remotely.

1. Introduction

Post-traumatic Stress Disorder (PTSD) may develop when a person is exposed to a traumatic event, either directly or indirectly, involving actual or threatened death, including serious injury and sexual violence (U.S. Department of Veterans Affairs, 2019). Facing a trauma is not uncommon; 50% to 60% of U.S. adults experience at least one trauma in the course of their lives (U.S. Department of Veterans Affairs, 2018). However, not all develop PTSD. According to the National Comorbidity Survey Replication (NCS-R), the estimated lifetime prevalence of PTSD among U.S. adults was 6.8% (Kessler et al., 2005). Using diagnostic criteria from the Diagnostic and Statistical Manual of Mental Disorders – 5th edition (DSM-5; American Psychiatric Association [APA], 2013), Kilpatrick et al. (2013) estimated the lifetime prevalence of PTSD to be 8.3% in a national sample of U.S. adults.

1.1. PTSD clusters

PTSD is a trauma and stress-related disorder characterized by four symptom clusters as defined by the DSM-5 (APA, 2013). Criterion A requires individuals to have experienced a traumatic event, defined as

an actual or threatened death, serious injury, or sexual violence either through direct exposure, witnessing the event as it happened to others, learning about the event, or experiencing repeated or extreme exposure to details of the event. An individual must exhibit symptoms from each of the four clusters in order to meet criteria for a diagnosis of PTSD. Cluster B is defined as intrusion symptoms associated with the traumatic event, such as recurrent distressing dreams or dissociative reactions (e.g., flashbacks). Cluster C is defined by avoidance symptoms, such as avoidance of or efforts to avoid distressing memories or external reminders. Cluster D relates to negative alterations in cognitions and mood, such as persistent and exaggerated negative beliefs about oneself, others, or the world, or feelings of detachment from others. Cluster E is concerned with arousal and reactivity symptoms, such as hypervigilance or irritable behavior and angry outbursts. Each of the cluster symptoms must be present for more than one month. Finally, an individual must experience either clinically significant distress or impairment in an important area of functioning, such as their occupation.

1.2. Problematic alcohol use

Within the United States, an estimated 88,000 people die from

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alcohol-related causes annually (Centers for Disease Control and Prevention, 2013). Alcohol related outcomes are the third leading preventable cause of death in the United States (Mokdad, Marks, Stroup, & Gerberding, 2004). The *DSM-5* classifies alcohol use disorder (AUD) with mild, moderate, and severe classifications. As opposed to the *DSM-IV*, AUD integrates the two previously distinct disorders of alcohol abuse and alcohol dependence. AUD is characterized by an inability to stop or control alcohol use despite adverse social, occupational, or health consequences (National Institute on Alcohol Abuse and Alcoholism [NIAAA], 2017). Institutions, such as the National Institute on Alcohol Abuse and Alcoholism (NIAAA), further define drinking patterns or episodes that may not qualify as an AUD. Binge drinking brings an individual's blood alcohol concentration (BAC) to 0.08 g/dL; bingeing is defined as five drinks for men and four drinks for women within an approximate two-hour window (NIAAA, n.d.).

1.3. PTSD and alcohol use

PTSD and harmful alcohol use, including alcohol use disorder, frequently co-occur (Possemato et al., 2015). Epidemiological studies estimate 24% to 52% of those with PTSD also have a substance use disorder, most commonly AUD (Kessler, Sonnega, Bromet, Hughes, & Nelson, 1995; Mills, Teesson, Ross, & Peters, 2006). Research related to individuals with these co-occurring disorders has been ongoing since the 1980s (Khantzian, 1985).

1.3.1. Theoretical perspectives

Khantzian (1985, 1997) proposed the self-medication hypothesis to explain the high co-occurrence between psychiatric disorders, such as PTSD and substance use. This theory posits that drugs of abuse are used to relieve psychological suffering or distress brought about by symptoms of a psychiatric disorder (Khantzian, 1997). Subsequent research has shown support for the self-medication hypothesis for individuals diagnosed with PTSD and AUD (McFarlane, 1998; Stewart, 1996). In describing the relation between alcohol use and PTSD, Khantzian (1997) proposed that alcohol consumed in low to moderate doses could alleviate the emotional numbing and feelings of detachment associated with PTSD, and in higher doses, could lessen the intensity when PTSD-related emotions become overwhelming (emotional flooding). This hypothesis maintains that it is not the psychiatric disorder itself that leads to alcohol use, but rather the *distress* caused by symptoms of that disorder – particularly negative alterations in emotions and thoughts regarding the trauma.

While the self-medication hypothesis focuses on individual-level determinants of alcohol use, social-cognitive theory incorporates environmental factors, and the interaction between the individual and the environment (Alexander & Ward, 2018; Bandura, 1989). According to social-cognitive theory, alcohol use is a learned response to acute and chronic stressors, as well as the result of an individual's interpretation of those stressors (Bandura, 1986). This theory also stresses the importance of self-efficacy in moderating the association between stressors and behaviors (Bandura, 1989), such that the interpretation of affective and environmental cues in addition to an individual's ability to cope with stressors largely influences alcohol use (Possemato et al., 2015). Activation of self-efficacy and coping beliefs in response to cues, such as reminders of the trauma or elevated PTSD symptoms, has been shown to predict alcohol use (Possemato et al., 2015). Lower perceived self-efficacy in coping with trauma-related cues “may produce more psychological distress because individuals feel they are unable to control themselves or their surroundings” (Alexander & Ward, 2018, p. 6; Benight & Bandura, 2004). Self-efficacy to resist drinking, serving as a moderator variable, may determine whether self-medication by alcohol use is initiated and/or maintained following a trauma or exposure to trauma cues (Alexander & Ward, 2018).

The mutual maintenance model is an alternative explanation of the functional relationship between PTSD symptoms and alcohol use.

Similar to the self-medication hypothesis, the mutual maintenance model also proposes that PTSD symptoms lead to alcohol use. However, the mutual maintenance model further proposes that alcohol use in turn exacerbates or maintains PTSD symptom severity (Kaysen et al., 2014; McFarlane et al., 2009; Possemato et al., 2015). Alcohol use on a given day could exacerbate PTSD symptoms the following day because of “withdrawal and other physical alcohol effects associated with heavy drinking (e.g. increased irritability, poor sleep quality) or greater social or intra-personal consequences (e.g. detachment from others, feeling guilt or shame)” (Simpson, Stappenbeck, Luterek, Lehavot, & Kaysen, 2014, p. 245).

1.3.2. PTSD clusters and alcohol use

For an individual to meet criteria for a diagnosis of PTSD, they must exhibit two of the seven negative cognition and mood symptoms (among other cluster criteria). Numbing symptoms overlap with depression, another disorder linked with alcohol use (Grant & Harford, 1995; Hasin, Goodwin, Stinson, & Grant, 2005; Jakupcak et al., 2010). Kaysen et al.'s (2007) study of PTSD in women who recently experienced physical violence found symptoms of negative affect and affect regulation were important determinants of heavy episodic drinking. In another study investigating alcohol use and PTSD, emotional numbing was the only PTSD symptom cluster significantly associated with the probability of consuming alcohol (Jakupcak et al., 2010). Jakupcak et al. (2010) interpreted these results as showing a propensity to drink to improve mood or as a method to facilitate detachment. These results and conclusions are consistent with Khantzian's self-medication hypothesis of regulating distress, and consequently emotion.

1.4. Ecological momentary assessment (EMA)

Research on the relationship between PTSD symptoms and drinking has typically relied on self-report measures that ask participants to answer questions about the past week, month, or several months (Johnson, Westermeyer, Kattar, & Thuras, 2002). National surveys, such as the National Comorbidity Survey, have also been employed to gather information. One difficulty in using these retrospective approaches is that they derive aggregate measures that may not capture details about fluctuating patterns of PTSD symptomatology and drinking behaviors (Johnson et al., 2002; Possemato et al., 2015). This more granular information could be used to evaluate the adequacy of competing theories about the co-occurrence of PTSD symptom experiences and alcohol use. EMA is a collection of assessment techniques that can be used to capture the temporal associations between PTSD symptoms and drinking because symptoms and behaviors are measured in real time, as they occur (Shiffman, Stone, & Hufford, 2008).

As introduced by Stone and Shiffman (1994) and defined by Shiffman et al. (2008), the term EMA represents an assortment of “methods using repeated collection of real-time data on subjects' behavior and experience in their natural environments” (p. 3). To better understand its name, “ecological” refers to the collecting of data as individuals go about their daily lives (Shiffman et al., 2008). “Momentary” highlights the capturing of the individual's current state when being assessed, as opposed to recalling over long periods of time (Shiffman et al., 2008). Researchers schedule assessments based on variables of interest and the purpose of study, as well as hypotheses about frequency of behavior and rates of fluctuation. In this paper, we use the term EMA as defined by Shiffman et al. (2008), meaning that it is not tied to a particular technology (such as cell phones) but can pertain to any study that shares the characteristics above, to include daily diary studies (using paper and pencil, mobile devices, or interactive voice response (IVR) systems), as well as studies that use more intensive assessment schedules (multiple assessments per day at random or fixed times).

Central to the development of EMA methods observed in this review was the creation of the Experience Sampling Method by

Czikszenmihalyi and colleagues (DeVries, 1992; Hektner, Schmidt, & Csikszentmihalyi, 2007; Shiffman et al., 2008). This innovation in collecting data initially used pagers to randomly notify individuals to complete diary cards (Shiffman et al., 2008). As technology advanced, so did study methodologies within EMA research. Participants monitored their symptoms using: IVR (calling a toll-free telephone number), personalized digital assistants (PDAs), automatic text messages, and installed applications on their smartphones. Regardless of the specific tools used, EMA is preferred when studying the relationships between multiple variables in real-time as the method involves recording data close in time to experience with no reliance on accessibility of long-term memories. This is especially important when studying mental health symptoms, such as PTSD, and substance use, as they fluctuate day-to-day, and even within a day. Observing the specific symptomatic and environmental conditions that precede and maintain alcohol use for individuals with PTSD is critical to refining existing behavioral theories and developing targeted interventions.

1.5. Rationale

EMA is a relatively new methodology within PTSD research, but these techniques have shown promise for broadening the description and understanding of how and when PTSD symptom experiences and alcohol use co-occur. While a review of EMA studies of substance use has been conducted, a review of studies investigating the association between PTSD and alcohol use has not yet been completed. A narrative review of this literature may facilitate identification of future directions for research and theory development that may inform more individualized treatment approaches for individuals struggling with PTSD and problematic alcohol use.

2. Methods

To identify a range of studies that used repeated measures of PTSD symptoms and alcohol use in real or close-to-real time in the context of respondents' natural environments, a literature review was conducted using Pubmed (US National Library of Medicine, National Institutes of Health) to include the following broad search terms: "Ecological Momentary Assessment," "EMA," "momentary assessment," "experience sampling," "PTSD," "post-traumatic," "post-traumatic stress disorders," "post traumatic stress disorder," "posttraumatic stress disorder," "ethanol," and "Alcohol." Similar searches were also made on PsycINFO and Embase (Supplementary materials). Additional searches were made using a general web browser (e.g. Google Scholar) and the university's electronic library archives. Inclusion criteria for studies included in this review were: (1) use of ecological momentary assessment as the method for gathering data on alcohol use and/or craving in populations with both problematic alcohol use and PTSD, and the inclusion of an assessment of both PTSD symptoms and at least one alcohol use variable during EMA; and (2) at screening, participants were required to meet study criteria for a) elevated PTSD symptoms or trauma exposure, and b) elevated alcohol use (i.e., participants were selected based on elevated PTSD symptoms and elevated alcohol use). The second criterion was used because it would be expected to increase variability in measures of PTSD symptomatology and alcohol use, which would be expected to increase sensitivity of analyses.

All publication dates were included in review; studies included were published between 2005 and 2017. Note that two studies (Sanjuan, Pearson, Poremba, Amaro, & Leeman, 2019; Simons et al., 2018), both of which explored the association between PTSD symptoms and alcohol-related variables, are referenced in the discussion, but were excluded from the review as they failed to meet this review's inclusion criterion (2) (Simons et al., 2018, and Sanjuan et al., 2019 did not select for participants with elevated PTSD symptoms/trauma exposure and elevated alcohol use, respectively). A further study (Biggs et al., 2019), which did not report the association between PTSD symptoms and

alcohol-related variables, was excluded because participants were not selected for elevated alcohol use (and consequently drinking rates were low).

3. Research

The studies listed in Table 1 met the above inclusion criteria. They are reviewed and discussed according to four themes: (1) methodological considerations (i.e., assessment of compliance, reactivity, and correspondence between EMA and retrospective data); (2) associations between PTSD symptoms and alcohol-related variable/s; (3) moderators of the above associations; and (4) mediators of associations. Several studies are included under more than one section.

3.1. Methodological considerations

An important issue in EMA research is the extent to which completion of an EMA protocol may cause changes in the phenomena under investigation, termed reactivity (McCarthy, Minami, Yeh, & Bold, 2015; Shiffman, 2015). This is best examined with the use of a randomized group trial in which one group does not complete EMA or completes momentary assessments on a different schedule. Simpson, Kivlahan, Bush, and McFall (2005) randomized participants with comorbid PTSD and AUD into one of three groups: daily IVR for 28 days vs. weekly IVR for 4 weeks vs. no-monitoring control. Participants in the IVR conditions completed assessments of PTSD symptoms, craving, and alcohol use according to the defined schedules. Most participants indicated the IVR system was manageable and reported no effects from calling in and reporting their symptoms on their urges to drink, actual drinking, and PTSD symptoms (Simpson et al., 2005). Crucially, there was no evidence that group membership (i.e., schedule of assessment) caused changes in PTSD symptoms and alcohol use variables as assessed in the laboratory.

In addition to the question as to whether EMA monitoring causes changes in reports of variables under investigation (assessed by a randomized trial), participants' perceptions of the effect of EMA monitoring may also be of interest. Expanding on the research done by Simpson et al. (2005), Possemato et al. (2012) increased their protocol requirements from calling in to the IVR system once a day to calling in four times a day. Those participants who did complete the 4-week follow-up interview provided ratings on a 5-point Likert scale (1 = decreased a lot to 5 = increased a lot) regarding how they perceived monitoring to affect their urges to drink, drinking, drug use, tobacco use, and trauma/PTSD symptoms over the past 28 days. The majority of participants (61%) perceived an increase in their PTSD symptomatology over the study period. However, participants' perceptions were inconsistent with standardized self-report assessments of symptoms throughout the study. Data from IVR assessments revealed a significant decrease in PTSD symptoms over time. In addition, Possemato et al. (2012) sought to explore what factors may predict compliance in their sample of Iraq and Afghanistan War veterans who reported hazardous drinking and met subthreshold criteria for PTSD. Overall, protocol compliance was high, with an average of 96 out of 112 IVR assessments being completed over a 28-day period (Possemato et al., 2012). Along with receiving generally positive feedback about the IVR system, these results demonstrate that study participants were highly compliant with a more intensive protocol. They also found several demographic, clinical, and research feedback factors that predicted protocol compliance: being older than 24 years old; being employed full-time; being more educated; reporting fewer substance use disorder diagnoses; reporting fewer binge drinking episodes; reporting fewer avoidance symptoms; and being motivated to participate in the study to improve themselves.

With respect to alcohol consumption, studies have also assessed the degree of correspondence between EMA data and widely used assessments such as the timeline follow-back. Simpson et al. (2011) evaluated the agreement between daily IVR monitoring and retrospective reports,

Table 1
Summary of studies reviewed.

Study, country, and design	Participants	Independent variables	Dependent variables	Moderator/Mediator variables	EMA protocol	Main findings
Black et al. (2018) USA Correlational	28 male post-9/11-era veterans who scored 24+ /80 on the PCL-5 (PTSD Checklist) & reported 1+ binge drinking event in past 28 days Mean age = 31.4	EMA: Change in PCL-5 scores from previous assessment	EMA: # standard alcoholic drinks in past 2-h	Impulsivity (Barratt Impulsivity Scale-11) (Moderator)	Hardware/software: Personal smart phones; Research Electronic Data Capture survey software Frequency: 3/day for 28 days Trigger: Automated text messages randomly sent every five-hour interval between 7 am and 10 pm Compliance: ~74.7% Hardware/software: IVR Frequency: 1/day for 31 days (post-intervention period of larger study) Trigger: Participants told to make a daily call regarding the previous day Compliance: IVR responses on 93.3% of the reporting days.	Change in PCL-5 associated with number of alcohol drinks consumed in past 2-h (cross-sectional, within-); Association ↑ for participants who scored higher on trait impulsivity
Campbell et al. (2017) USA Correlational	65 individuals (31 M/34 F) with comorbid alcohol dependence and PTSD (DSM-IV criteria) Mean age = 45.2	Lab: Retrospective report of PTSD "over the previous month" (PCL-C, 17 items); EMA: Sum of no. of standard drinks of beer, wine, liquor consumed the "previous day".	EMA: PTSD symptoms "over the past day" (0-8 scale for 12 items, 2 reexperiencing, 2 avoidance, 3 numbing, 4 hyperarousal).	Daily alcohol consumption (Moderator)	Hardware/software: IVR Frequency: 1/day for 14 days Trigger: Participants made calls to the IVR system during a six-hour window from 6 pm to 12 am Compliance: IVR responses on 73% of the reporting days.	Agreement between retrospective & daily (IVR) PTSD ratings range from <i>pseudo-R</i> ² of 38% to 56%; Daily alcohol consumption weakened agreement between daily & retrospective reports of reexperiencing and avoidance symptoms; ↑ daily alcohol consumption (vs. subject average) predicted ↑ of all PTSD symptoms (within-); Participants who drank more than sample average reported ↑ avoidance and numbing symptoms (between-) NA mediated relationship between PTSD symptoms and same-day, not next-day, alcohol use; Alcohol use & craving ↑ on days with increased NA; Stronger associations between PTSD symptoms, negative affect, craving, & alcohol use for participants with AUD (vs without); Last-night drinking predicted ↑ next-day PTSD symptoms in AUD PTSD symptoms during day correlated with ↑ alcohol use & problems that night (within-); PTSD symptoms associated with ↑ alcohol problems (between-); Association between PTSD & problems persist controlling for use; Higher emotional intelligence → lower negative urgency → ↓ PTSD symptoms → ↓ alcohol problems; No evidence for cross-level moderation
Cohn et al. (2014) USA Correlational	54 women who reported a rape in past five years & not in treatment for mental health/substance use problems Mean age = 26	EMA: PTSD symptoms "last 24 h" (7 items from PCL-C, "yes"/"no") (Deviation score)	EMA: Alcohol use (sum of standard drinks of beer, wine, and liquor reported on given date before & after IVR); desire to drink (0-4 scale)	Negative Affect (Deviation score) "today" (NA) (Mediator); Lifetime AUD (Moderator)	Hardware/software: IVR Frequency: 1/day for 14 days Trigger: Participants made calls to the IVR system during a six-hour window from 6 pm to 12 am Compliance: IVR responses on 73% of the reporting days.	NA mediated relationship between PTSD symptoms and same-day, not next-day, alcohol use; Alcohol use & craving ↑ on days with increased NA; Stronger associations between PTSD symptoms, negative affect, craving, & alcohol use for participants with AUD (vs without); Last-night drinking predicted ↑ next-day PTSD symptoms in AUD PTSD symptoms during day correlated with ↑ alcohol use & problems that night (within-); PTSD symptoms associated with ↑ alcohol problems (between-); Association between PTSD & problems persist controlling for use; Higher emotional intelligence → lower negative urgency → ↓ PTSD symptoms → ↓ alcohol problems; No evidence for cross-level moderation
Gaher et al. (2014) USA Correlational	90 OIF/OEF veterans aged 18-50 who drank 1+ drink/week for past 3 months & experienced PTSD symptoms in past months Mean age = 28.90	EMA: PTSD symptoms (modified 17-item PCL) (Mean & Deviation scores); Emotional intelligence	EMA: # drinks past 30 mins (0-6+ drinks); how intoxicated (1-11); Morning report (MR): # drinks previous night; "Nighttime drinking" - Mean of RA & MR data; Alcohol problems (Random & MR) (Moderators)	Negative Urgency & PTSD symptoms (Mediators); Emotional Intelligence & Negative Urgency (Moderators)	Hardware/software: Palmtop computers; PMAIT Software Frequency: 8/day for 14 days Trigger: Participants randomly alerted to complete assessments between the hours of 10 am and 2 am; Morning reports (self-initiated) Compliance: 70.37% of random prompts, 88% of morning assessments, 92% of evening assessments	PTSD symptoms during day correlated with ↑ alcohol use & problems that night (within-); PTSD symptoms associated with ↑ alcohol problems (between-); Association between PTSD & problems persist controlling for use; Higher emotional intelligence → lower negative urgency → ↓ PTSD symptoms → ↓ alcohol problems; No evidence for cross-level moderation
Hruska et al. (2017) USA Correlational	36 traumatic injury victims (27 M/9 F) in early recovery Mean age = 34	EMA: PTSD symptoms (6-item PCL short form) (Deviation scores) (Also DV in select analyses)	EMA: Alcohol craving (3-items), alcohol consumption (# drinks since last assessment), negative drinking consequences (DrInC since last assessment), PTSD symptoms (Also IV in select analyses)	Assessment Timing (morning, afternoon, night) (Moderator)	Hardware/software: PDA Frequency: 3/day for 7 days Trigger: PDA randomly beeped to alert participants to complete assessments between the hours of 10.00 and 19.30 Compliance: Response rate of 72.2%	PTSD symptoms cross-sectionally associated with ↑ alcohol craving/negative consequences (especially at night for consequences) (within-); Nighttime PTSD symptoms prospectively associated with ↑ negative drinking consequences the following morning; No evidence that craving, use, or consequences prospectively associated with PTSD symptoms

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Table 1 (continued)

Study, country, and design	Participants	Independent variables	Dependent variables	Moderator/Mediator variables	EMA protocol	Main findings
Kaysen et al. (2014) USA Correlational	136 college drinkers with history of sexual victimization & 38 college drinkers with no past trauma history (All reported 4+ drinks on one occasion at least twice in past month) (females) Mean age = 20.04	EMA: PTSD symptoms ("how much each symptom bothered them in past 24 h"); 3 factors (trauma subscale, dysphoric subscale, hyperarousal subscale); negative affect, positive affect, arousal "at time of the assessment" derived from modified PANAS	EMA: Alcohol use "in the past 24 h", craving (3-items, 0–8 scale) ("since the last assessment")	Trauma status; Weekend- vs. Weekday (Moderators)	Hardware/software: PDA Frequency: 2/day for 30 days Trigger: Self-selected 2-h block of time in both the morning and evening. Alarm set for beginning of window. Compliance: 68.9% of morning drinks on drinking days (within-); assessments and 64.8% of evening assessments	No association between baseline trauma status and alcohol craving or use; Deviation negative affect & Deviation arousal associated with craving (within-); Deviation PCL dysphoria and Deviation arousal associated with reduced count of drinks on drinking days (within-); Deviation positive affect associated with increased likelihood of drinking on that day (within-); No evidence for moderation Participants reported fewer drinks on Form-35 vs IVR; Strong correlations between IVR & Form-35 data at aggregate level (all days, and by week); Trigger: Participants told to make a daily call. Pager reminded them to complete call Compliance: Response rate of 95%
Krennek et al. (2016) USA Correlational	54 individuals (28 M/26 F) with comorbid alcohol dependence and PTSD (DSM-IV criteria) Mean age = 45.3	Lab: Retrospective report of alcohol use (Form-35) – drinking days, heavy drinking days, total drinks	EMA: Alcohol use (number of standard drinks the previous day) on IVR;	None	Hardware/software: IVR and accompanying pager system Frequency: 1/day for 35 days Trigger: Participants told to make a daily call. Pager reminded them to complete call Compliance: Response rate of 95%	No evidence for moderation Participants reported fewer drinks on Form-35 vs IVR; Strong correlations between IVR & Form-35 data at aggregate level (all days, and by week); Day-to-day correspondence was "moderate to weak"; Over 35 days, average absolute difference of 2.9 drinks per day (range 0.1–23.3); Lower correspondence for men and participants who drank more. Compliance: Average of 96/112 (86%) IVR assessments completed; Decreases in PTSD symptoms in lab from BL to FU; Older > 24, full-time employment, more education, less binge drinking, less avoidance symptoms, perceived benefit from study predicted better compliance Deviation PTSD symptoms associated with ↑ drinking within 3-h block (within-) (cross-sectional); Deviation PTSD symptoms generally associated with ↓ drinking within following 3-h block (within-) controlling for lagged drinking (prospective) but ↑ drinking when analysis subset to evening assessment; Deviation alcohol use associated with ↓ PTSD symptoms in the following 3-h block (within-) controlling for lagged alcohol use (prospective); Avoidance Coping strengthened, Self-efficacy to resist drinking weakened, association between PTSD & later drinking IVR system was manageable; No effect of Group on PACS, actual drinking, PTSD symptoms.
Possemato et al. (2012) USA Correlational	50 Iraq & Afghanistan War veterans (39 M/11 F) who reported hazardous drinking (AUDIT ≥ 8) & at least subthreshold symptoms of combat-related PTSD Mean age = 30	Lab: Demographics, military and clinical characteristics; Participant feedback items (FU) (e.g., perceived benefit)	Lab: Symptom change (CAPS) from BL to 4-wk FU; EMA: Compliance (# of missed calls); PTSD symptoms (0–3 scale for 17 items); alcohol use (# standard drinks since previous call)	None	Hardware/software: IVR Frequency: 4/day for 28 days Trigger: Software automatically initiated call during 4 call blocks Compliance: Response rate of 86%	Compliance: Average of 96/112 (86%) IVR assessments completed; Decreases in PTSD symptoms in lab from BL to FU; Older > 24, full-time employment, more education, less binge drinking, less avoidance symptoms, perceived benefit from study predicted better compliance Deviation PTSD symptoms associated with ↑ drinking within 3-h block (within-) (cross-sectional); Deviation PTSD symptoms generally associated with ↓ drinking within following 3-h block (within-) controlling for lagged drinking (prospective) but ↑ drinking when analysis subset to evening assessment; Deviation alcohol use associated with ↓ PTSD symptoms in the following 3-h block (within-) controlling for lagged alcohol use (prospective); Avoidance Coping strengthened, Self-efficacy to resist drinking weakened, association between PTSD & later drinking IVR system was manageable; No effect of Group on PACS, actual drinking, PTSD symptoms.
Possemato et al. (2015) USA Correlational	143 OIF/OEF combat veterans (126 M/17 F) in VA primary care who reported hazardous drinking (AUDIT ≥ 8) & at least subthreshold symptoms of combat-related PTSD Mean age = 30.1	EMA PTSD symptoms (0–3 scale for 17 items); assessment number (time)	EMA: Alcohol use (# standard drinks since previous call)	Avoidance Coping & Self-efficacy to resist drinking (Moderators)	Hardware/software: IVR Frequency: 4/day for 28 days Trigger: Software automatically called during 4 call blocks Compliance: Response rate of 81%	Compliance: Average of 96/112 (86%) IVR assessments completed; Decreases in PTSD symptoms in lab from BL to FU; Older > 24, full-time employment, more education, less binge drinking, less avoidance symptoms, perceived benefit from study predicted better compliance Deviation PTSD symptoms associated with ↑ drinking within 3-h block (within-) (cross-sectional); Deviation PTSD symptoms generally associated with ↓ drinking within following 3-h block (within-) controlling for lagged drinking (prospective) but ↑ drinking when analysis subset to evening assessment; Deviation alcohol use associated with ↓ PTSD symptoms in the following 3-h block (within-) controlling for lagged alcohol use (prospective); Avoidance Coping strengthened, Self-efficacy to resist drinking weakened, association between PTSD & later drinking IVR system was manageable; No effect of Group on PACS, actual drinking, PTSD symptoms.
Simpson et al. (2005) USA Randomized Groups	98 individuals (89 M/9 F) with comorbid PTSD & AUD Mean age = 45.8	Study condition (Randomized Groups: daily IVR for 28 days vs. weekly IVR for 4 weeks vs. no-monitoring control condition); (IVR assessed alcohol craving, substance use, emotional well-being, & PTSD symptoms)	Compliance with IVR protocols (EMA); experiences with IVR (lab); Urge to drink (Pennsylvania Alcohol Craving Scale) (PACS) (lab); # drinking days & total drinks (Form-28) (lab); PTSD symptoms (17-items PCL) (lab)	None	Hardware/software: IVR Frequency: 1/day for 28 days or 1/week for 4 weeks or complete a 28-day follow-up assessment Trigger: Participants told to make a daily/weekly call. Incentives provided to both daily/weekly conditions Compliance: Response rate of 77.8% (daily condition) & 74.1% (weekly condition)	Compliance: Average of 96/112 (86%) IVR assessments completed; Decreases in PTSD symptoms in lab from BL to FU; Older > 24, full-time employment, more education, less binge drinking, less avoidance symptoms, perceived benefit from study predicted better compliance Deviation PTSD symptoms associated with ↑ drinking within 3-h block (within-) (cross-sectional); Deviation PTSD symptoms generally associated with ↓ drinking within following 3-h block (within-) controlling for lagged drinking (prospective) but ↑ drinking when analysis subset to evening assessment; Deviation alcohol use associated with ↓ PTSD symptoms in the following 3-h block (within-) controlling for lagged alcohol use (prospective); Avoidance Coping strengthened, Self-efficacy to resist drinking weakened, association between PTSD & later drinking IVR system was manageable; No effect of Group on PACS, actual drinking, PTSD symptoms.

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Table 1 (continued)

Study, country, and design	Participants	Independent variables	Dependent variables	Moderator/Mediator variables	EMA protocol	Main findings
Simpson et al. (2011) USA Correlational	25 outpatients (23 M/2 F) with AUD and most screening positive for PTSD Mean age = 48.0	Lab: Number of daily standard drink units (SDUs), number of drinking days, reported heavy drinking days (Form-28)	EMA: Number of drinks consumed, number of drinking days, number of heavy drinking days	Week of study (Moderator; interaction not formally tested)	Hardware/software: IVR Frequency: 1/day for 28 days Trigger: Participants told to make a daily call. Compliance: Response rate of 94% Days on Form-28 (vs. IVR) PTSD symptoms associated with same-day craving (cross-sectional); PTSD symptoms not associated with next-day craving (prospective); Greater distress from nightmares, emotional numbing, & hypervigilance predicted ↑ next-day craving; greater anger/irritability predicted ↓ next-day craving; Craving not associated with next-day PTSD symptoms (prospective)	Strong correlation between IVR and Form-28 on days drinking & total SDUs in whole sample (N = 25) & drinkers (n = 7); Day-to-day correlation in drinkers modest, but stronger for the most recent week; Drinkers reported more SDUs & drinking days on Form-28 (vs. IVR) PTSD symptoms associated with same-day craving (cross-sectional); PTSD symptoms not associated with next-day craving (prospective); Greater distress from nightmares, emotional numbing, & hypervigilance predicted ↑ next-day craving; greater anger/irritability predicted ↓ next-day craving; Craving not associated with next-day PTSD symptoms (prospective)
Simpson et al. (2012) USA Correlational	29 individuals diagnosed with an AUD and beginning a new episode of treatment for AUD; 26/29 screened positive for PTSD; socially-unstable (~44% homeless during study) Mean age = 48.0	EMA: PTSD symptoms (modified 7-item PCL); upsetting dreams; upset due to reminders; avoiding reminders; emotionally numb; hypervigilance; increased startle response; anger/irritability)	EMA: Alcohol craving (1-item; 0-7 scale)	None	Hardware/software: IVR Frequency: 1/day for 28 days Trigger: Participants told to make a daily/weekly call. Incentives provided to both daily/weekly conditions Compliance: Sample provided data for at least 50% of days of 28-day monitoring period. Response rate of 91.3%	PTSD symptoms predicted same-day (cross-sectional) & next-day (prospective) alcohol use (within-); Alcohol use predicted same-day (cross-sectional) & next-day (prospective) PTSD symptoms (within-); Those with higher (vs. lower) coping drinking motives & lower (vs. higher) enhancement motives had greater ↑ in alcohol consumption the same day they experienced a 1-unit increase in PTSD symptoms
Simpson et al. (2014) USA Correlational	86 civilians & veterans (44 M/42 F) with comorbid PTSD & alcohol dependence (AD) who indicated a desire to decrease alcohol use Mean age = 44.7	EMA: PTSD symptoms (12-items, how bothered they were during the previous day) (also DV in select analyses) (Deviation score)	EMA: Alcohol use (total number of standard drinks past day) (also IV in select analyses) (Deviation score)	Coping & Enhancement Drinking Motives (Moderators);	Hardware/software: IVR Frequency: 1/day for 6-20 days (BI period of larger study) Trigger: Participants told to make a daily call regarding the previous day Compliance: Sample provided data for at least 50% of days of 28-day monitoring period. Response rate of 95.3%	PTSD symptoms predicted same-day (cross-sectional) & next-day (prospective) alcohol use (within-); Alcohol use predicted same-day (cross-sectional) & next-day (prospective) PTSD symptoms (within-); Those with higher (vs. lower) coping drinking motives & lower (vs. higher) enhancement motives had greater ↑ in alcohol consumption the same day they experienced a 1-unit increase in PTSD symptoms
Wilson et al. (2017) USA Correlational	86 civilians & veterans (44 M/42 F) with comorbid PTSD & alcohol dependence (AD) who indicated a desire to decrease alcohol use. Mean age = 44.7	EMA: Alcohol use (number of standard drinks prior day)	EMA: Alcohol-related problems (1-item, 0-9 scale; "Yesterday, to what extent did you experience any negative consequences or problems related to your drinking?")	Mean PTSD symptoms (between-) & Deviation PTSD symptoms (within-) (Moderators)	Hardware/software: IVR Frequency: 1/day for 4-16 days (BI period of larger study) Trigger: Participants told to make a daily call regarding the previous day Compliance: Sample provided data for at least 50% of days of 28-day monitoring period	As within- and between- PTSD symptoms ↑, association between number of drinks consumed & alcohol-related problems ↓

Note: IVR = interactive voice response. PDA = personal digital assistant; OEF = Operation Enduring Freedom; OIF = Operation Iraqi Freedom.

assessed using Form-28 (a modified version of Form-90; Miller & Boca, 1994) at their follow-up appointment. Aggregated over the 28 days, when examining the total number of days drinking, the total standard drinking units (SDUs), and total number of heavy drinking days, data from the two methods were highly correlated across all subjects ($r_s = 0.90, 0.87,$ and $0.98,$ respectively) (Simpson et al., 2011). This correlation decreased when examining day-to-day correspondence (e.g., $r = 0.33$ for number of daily SDUs reported among drinkers) with the strongest correlation ($r = 0.69$ for number of daily SDUs) found for the final week of the study (the week prior to assessment by Form-28). Participants reported higher rates of total alcohol use and heavy drinking on the Form-28 than with the IVR monitoring.

Krenek, Lyons, and Simpson (2016) also found good correspondence between daily and retrospective assessments of alcohol use when examined at the aggregate level. Consistent with the findings of Simpson et al. (2011), day-to-day correlations were moderate (Krenek et al., 2016). Additional analyses found that men exhibited greater discrepancies than women in their recollection of drinking days (Krenek et al., 2016). Participants reported fewer drinking days on Form-28 than using IVR.

One study assessed degree of agreement between PTSD symptoms assessed daily during IVR and PTSD symptoms assessed retrospectively over the previous month (Campbell, Krenek, & Simpson, 2017). Using a multilevel modeling approach, reports of reexperiencing ($pseudo-R^2 = 54\%$) and numbing symptoms ($pseudo-R^2 = 56\%$) showed better agreement than reports of arousal ($pseudo-R^2 = 44\%$) and avoidance symptoms ($pseudo-R^2 = 38\%$). Alcohol consumption did not significantly moderate the agreement between IVR and retrospectively assessed total PTSD symptoms ($pseudo-R^2 = 54\%$), but was associated with weaker agreement between IVR and retrospective reports of re-experiencing and avoidance symptoms.

3.2. Association between momentary PTSD symptoms & alcohol-related variables

The association between PTSD symptoms and alcohol craving was examined in a sample of 29 individuals with an AUD, 26 of whom screened positive for PTSD (Simpson, Stappenbeck, Varra, Moore, & Kaysen, 2012). Results showed that the level of PTSD symptoms recorded each day was positively associated with alcohol craving. Hyperarousal symptoms, such as anger/irritability and startle, were most strongly associated with same-day alcohol craving, and next-day craving was strongly predicted by the previous night's PTSD-associated sleep disturbance (i.e. nightmare), increase in emotional numbing, or hypervigilance (Simpson et al., 2012). The data did not reveal evidence that alcohol craving predicted increases in PTSD symptoms the following day.

Kaysen et al. (2014) explored associations between alcohol use and trauma history, PTSD symptoms, and affect in a sample of college women with and without sexual victimization histories. The study found no significant between-group differences in drinking behavior (i.e. drinking urge, daily drinking, amount of drinking on drinking days). Kaysen et al. (2014) is one of few studies to examine associations between subscales derived from the PCL (Specific version; PCL-S; Weathers, Litz, Herman, Huska, & Keane, 1993) (trauma subscale, dysphoria subscale, hyperarousal subscale) and alcohol-related variables, as well as associations between three factors derived from a modified PANAS (negative affect, positive affect, arousal) and alcohol-related variables. The dysphoria subscale (from the PCL) was comprised of the following symptoms: "sleep disturbance, irritability, impaired concentration, impaired trauma collection, loss of interest, detachment, restricted affect, and sense of foreshortened future" (Simms, Watson, & Doebbeling, 2002, p. 644).

Urges to drink were stronger on days in which participants reported greater negative affect and arousal than their person-specific average (Kaysen et al., 2014, Fig. 1). In a count model (Kaysen et al., 2014,

Fig. 2), participants who reported generally high levels of arousal reported a lower count of drinks on drinking days, and days with higher levels on the dysphoria subscale (from the PCL) and higher levels of arousal (from the modified PANAS) (vs. the subject-specific average) were associated with a lower count of drinks on drinking days. The negative association between dysphoria and drinking is contrary to expectations, and Kaysen et al. (2014) suggested that "dysphoric symptoms may also be related to symptoms of depression, including social isolation, decreased behavioral activation, or increased somnolence, which together may result in fewer opportunities to drink in a college setting, in which most alcohol access is through social provision in party settings" (p. 68). In general, different subscales of the PCL, as well as different factors associated with the PANAS, may have different associations with urges/drinking, and this should be further investigated.

In a sample of 86 civilians and veterans with comorbid PTSD and alcohol dependence, Simpson et al. (2014) used EMA methodology to test both the self-medication and mutual maintenance models of alcohol use. The study found greater support for the self-medication model by demonstrating that on days when participants experienced higher overall PTSD symptoms, they reported drinking a greater number of drinks that same day and the next day (PTSD → Alcohol). More specifically, a 1-unit increase in PTSD symptom severity was associated with a 20% increase in drinking that day and a 7% increase the next day (Simpson et al., 2014). While there was less support for the mutual maintenance model, Simpson et al. (2014) did find that the amount of alcohol consumed was modestly associated with same-day PTSD symptom severity. However, this association did not carry over to next-day symptom severity.

Gaher et al. (2014) used EMA to analyze both within- and between-person associations between PTSD symptom severity, alcohol use, and alcohol-related problems among post-9/11 era veterans. Alcohol-related problems could include any of the following: feeling sick/vomiting, taking foolish risks, or getting in an argument or fight (Gaher et al., 2014). The researchers found that when participants experienced an increase in daytime PTSD symptoms, they drank more and reported more alcohol-related problems that night (PTSD → Alcohol). In addition, PTSD symptoms recorded on one day were also associated with alcohol-related problems "above and beyond the effect of drinking level" (Gaher et al., 2014, p. 14).

Possemato et al. (2015) studied the association between daily PTSD symptoms and alcohol use in 143 recent combat veterans, all of whom met at least subthreshold PTSD criteria. Unlike past EMA research, the researchers assessed symptoms and alcohol use four times daily and investigated if PTSD symptom severity was associated with drinking concurrently (i.e., within the same three-hour time block) and if PTSD symptoms predicted drinking (i.e., in the next three-hour time block or the following one after that) (Possemato et al., 2015). They found that increases in PTSD symptoms were associated with more drinking within the same three-hour time block, but not within the following time block (Possemato et al., 2015). However, an association between evening PTSD symptoms and subsequent overnight drinking was observed (PTSD → Alcohol; Possemato et al., 2015).

In a sample of 36 injury victims who were in the early phase of recovery from their traumatic physical injuries, Hruska, Pacella, George, and Delahanty (2017) assessed PTSD symptom severity, alcohol craving, alcohol use, and negative drinking consequences. As with other studies, Hruska et al. (2017) examined variables pertinent to the self-medication and mutual maintenance hypotheses and found that PTSD symptom severity was significantly associated with concurrent alcohol craving (Hruska et al., 2017). When looking prospectively, the strongest relationship between PTSD symptoms and negative consequences was found to be at night (PTSD → Alcohol) (Hruska et al., 2017).

Campbell et al. (2017) examined the associations between daily alcohol consumption (assessed during IVR) (treated as the independent

variable) and same-day PTSD symptoms assessed during IVR (treated as the dependent variable) in 65 individuals with co-morbid PTSD and alcohol dependence. When participants drank more than their subject-specific average, they reported higher levels of all PTSD symptoms (within-subject association). In addition, participants who generally drank more than the sample average also reported generally higher levels of avoidance and numbing symptoms (between-subject association).

Black, Cooney, Sartor, Arias, and Rosen (2018) followed 28 male post-9/11 era veterans for 28 days. The inclusion criteria required participants to have reported at least subthreshold PTSD symptomatology on the PTSD Checklist for DSM-5, and most of the veterans met criteria for a PTSD diagnosis. Changes in PTSD symptom severity from the previous assessment were associated with the number of drinks consumed during the past two hours (Black et al., 2018).

3.3. Moderator analyses

As noted in Table 1, many studies included analysis of variables hypothesized to moderate the association between PTSD symptoms and alcohol-related variables. Most commonly, researchers examined subject variables assessed at baseline (such as motives for drinking, history of AUD, and impulsivity) as moderator variables. Simpson et al. (2014) found significant moderating effects of both coping (i.e. cope with negative affect) and enhancement (i.e. drinking to increase positive affect) drinking motives. For those who had higher coping drinking motives, a 1-unit increase in PTSD symptom severity was associated with a 37% increase in alcohol use that day (Simpson et al., 2014). For those with low enhancement motives, a 1-unit increase in PTSD symptom severity increased alcohol use by 45% (Simpson et al., 2014). Social (i.e. drinking for positive social rewards) and conformity (i.e. drinking to fit in) drinking motives did not significantly interact with PTSD symptom severity to predict same-day drinking (Simpson et al., 2014). None of the drinking motives interacted with PTSD symptom severity in predicting next-day alcohol use.

Gaher et al. (2014) explored how resilience and vulnerability factors could serve as moderators of PTSD-alcohol use associations. Specifically, they examined the role of negative urgency and emotional intelligence (assessed at baseline) as moderator variables, but they did not find evidence for either variable to moderate the association between PTSD symptoms and alcohol use or alcohol problems (Gaher et al., 2014).

Cohn, Hagman, Moore, Mitchell, and Ehrlke (2014) examined whether history of an AUD moderated the association between PTSD symptoms and alcohol use among 54 women who experienced a sexual assault in the past five years. The association between PTSD symptoms and alcohol-related outcome variables was stronger for women with an AUD (61%) than for those women who did not have an AUD (Cohn et al., 2014). In that study, on days with greater PTSD symptoms, women with an AUD had a greater desire to drink and drank more than women without an AUD; however, this moderating impact of AUD diagnosis was not observed for next-day alcohol use. Cohn et al. (2014) also reported evidence that AUD moderated the association between alcohol use and subsequent PTSD symptoms. Specifically, alcohol consumed the previous night did predict increased PTSD symptoms the following day (Alcohol \rightarrow PTSD), but only for women with an AUD (Cohn et al., 2014).

Possemato et al. (2015) examined the moderating effects of avoidance coping and self-efficacy to resist drinking on the association between PTSD and alcohol use. Both variables were considered as possible moderators due to the role of cognition in the association between stressors and behavior outcomes, a key component of the social-cognitive theory (Possemato et al., 2015). Possemato et al. (2015) reported both variables moderated the relationship between PTSD symptoms and alcohol use. For participants who relied more on avoidance coping, the association between PTSD and alcohol use was strengthened

(Possemato et al., 2015). For participants who reported greater self-efficacy to resist drinking, the association between PTSD and alcohol use weakened, meaning they drank significantly less than those with an average level of self-efficacy (Possemato et al., 2015).

Black et al. (2018) examined the moderating effects of trait impulsivity on the association between change in PTSD symptoms and drinking. Impulsivity was measured using the Barratt Impulsiveness Scale-11 (BIS-11), which assessed general impulsiveness and individual components of impulsiveness, such as attentional, non-planning, and motor impulsiveness (Black et al., 2018). They reported that the association between change in PTSD symptoms and past 2-h alcohol use was stronger for participants who exhibited higher trait impulsiveness (Black et al., 2018).

While all the above studies examined baseline variables as moderator variables, Wilson et al. (2017) examined time-varying PTSD symptoms as a moderator variable. Specifically, they were interested in examining the moderating effect of within-person (daily symptoms) and between-person (overall severity) PTSD symptoms on the association between alcohol use and same-day alcohol-related problems. Alcohol-related problems were assessed using a single item in which participants reported on a 9-point Likert scale (0 = none at all to 8 = worse ever) the extent to which they experienced any negative consequences or problems relating to their drinking (Wilson et al., 2017). First, they found that both overall PTSD severity (between-) and daily PTSD symptom severity (within-) predicted self-reported alcohol-related problems that same day (Wilson et al., 2017), thereby demonstrating the expected positive association between PTSD symptoms and an alcohol-related variable.

More relevant here, as PTSD symptoms (both between- and within-person) increased, the association between number of drinks consumed and alcohol-related problems changed. Specifically, on days on which PTSD symptom severity was greater than a subject-specific average, more alcohol-related problems were reported on non-drinking and on moderate drinking days (3 drinks consumed) (but not on heavier drinking days) (Wilson et al., 2017). Thus, PTSD severity moderated the relationship between alcohol use and alcohol-related problems. Wilson et al. (2017) noted that individuals with high levels of PTSD severity may experience alcohol-related problems from even a small amount of alcohol, or that they engage in negative coping strategies that lead to negative outcomes regardless of the amount of alcohol consumed.

Finally, researchers have examined features of the timing of EMA assessments, such as day of week and time of day, as moderator variables. Kaysen et al. (2014) reported that day type (weekend vs. weekday) did not moderate the association between PTSD symptoms and alcohol-related variables. Hruska et al. (2017) found significant moderating effects of assessment time on the association between PTSD symptoms and study outcomes. PTSD symptoms were most strongly associated with increases in alcohol craving and negative consequences from drinking at the evening assessment (Hruska et al., 2017).

3.4. Mediator analyses

To the best of our knowledge, Cohn et al. (2014) conducted the only study examining variables that may mediate the association between PTSD symptoms and alcohol use. They focused on negative affect as the mediator. On days when participants experienced greater PTSD symptomatology, negative affect was higher. On days when negative affect was higher, both alcohol use and intensity to drink were greater. Negative affect was found to mediate the association between PTSD symptoms and same-day (but not next-day) alcohol use and desire to drink (Cohn et al., 2014). Cohn et al. (2014) also showed that negative affect did not mediate the association between alcohol consumed the previous night and PTSD symptoms the following day.

Whereas the analysis reported in Cohn et al. (2014) was a within-subject mediation analysis, Gaher et al. (2014) examined a between-subject mediation analysis in which PTSD symptoms served as a

mediator variable (rather than a predictor variable). Specifically, [Gaher et al. \(2014\)](#) reported that participants with higher emotional intelligence reported lower negative urgency, which in turn was associated with fewer PTSD symptoms (assessed by EMA), which was in turn associated with fewer alcohol problems (assessed by EMA). Thus, at a between-subjects level, PTSD symptoms mediated the association between negative urgency and alcohol problems.

4. Discussion

Findings from each of the four themes are summarized and discussed below.

4.1. Methodological considerations

Participants were generally compliant with completion of EMA assessments (detailed compliance data are reported in [Table 1](#)). Briefly, compliance ranged from 64.8% (evening assessment; [Kaysen et al., 2014](#)) to 95.3% ([Simpson et al., 2014](#)). Compliance exceeded 70% for all studies but one. In addition, there was little evidence from the studies reviewed that monitoring increased (or decreased) PTSD symptom or alcohol use. Nonetheless, participants may still perceive that monitoring may influence drinking or PTSD symptoms, and it may be useful to assess these perceptions. For alcohol use, when comparing retrospective self-reports to daily monitoring data, correspondence between the two methodologies was strong at the aggregate level in one study. At the day level, correspondence was more moderate, but may be stronger at the more recent timepoints ([Krenek et al., 2016](#); [Simpson et al., 2011](#)). This is consistent with data showing that memory of distal episodes of drug taking assessed in the laboratory can be unreliable (e.g., [Shiffman et al., 1997](#)), and underscores the utility of EMA when accurate and detailed temporal information is required (see also [Piasecki, 2019](#)). In general, the studies reviewed provided evidence that EMA methods can be applied in the populations sampled, and the use of EMA can provide more detailed information about events that fluctuate over time than typical self-report measures assessed in the laboratory.

4.2. Association between PTSD symptoms & alcohol-related variables

Overall, the studies provided strong support that PTSD symptoms are associated with alcohol-related variables ([Simpson et al., 2012](#); [Kaysen et al., 2014](#); [Simpson et al., 2014](#); [Gaher et al., 2014](#); [Black et al., 2018](#); [Cohn et al., 2014](#); [Hruska et al., 2017](#); [Campbell et al., 2017](#); but see [Sanjuan et al., 2019](#)). Notably, [Cohn et al. \(2014\)](#) did find that previous night's drinking predicted an increase in PTSD symptoms for the following day, though this association was only significant for individuals with an existing AUD. They suggested that when alcohol is consumed in greater quantities, it may worsen PTSD symptoms once the alcohol has worn off ([Cohn et al., 2014](#); [Tomlinson, Tate, Anderson, McCarthy, & Brown, 2006](#)). In addition, [Simons et al. \(2018\)](#), not included in the review, reported evidence for reciprocal associations between time-varying post-traumatic stress symptoms (PTSS) and alcohol dependence. In particular, increases in alcohol dependence syndrome predicted an increase in next-day PTSS.

Only a few studies ([Kaysen et al., 2014](#); [Simpson et al., 2012](#)) examined the complex relationship between PTSD symptom clusters and alcohol-related variables. While [Simpson et al. \(2012\)](#) reported that an increase in hypervigilance predicted greater alcohol craving, [Kaysen et al. \(2014\)](#) reported that an increase in intrusive symptoms as well as behavioral avoidance correlated more strongly with alcohol craving. Despite this discrepancy, [Simpson et al. \(2012\)](#) did find that intrusive symptoms during the night were associated with next-day alcohol craving, showing some common themes within this field of study. However, more research needs to be done before making general conclusions about patterns of associations between PTSD symptoms and alcohol-related variables.

Indeed, it is interesting that the extant non-EMA literature has also found differences in which specific PTSD symptom clusters are most strongly associated with alcohol use (i.e. [Kaysen et al., 2014](#); [Simpson et al., 2012](#)). In some studies, reexperiencing and hyperarousal symptoms predicted subsequent drinking ([Maguen, Stalaker, McCaslin, & Litz, 2009](#); [McFall, Mackay, & Donovan, 1992](#); [Read, Brown, & Kahler, 2004](#); [Simpson et al., 2014](#)). In others, avoidance and emotional numbing had a stronger association with drinking ([Jakupcak et al., 2010](#); [Kehle et al., 2012](#)). Many of these studies leading to these mixed findings used the three symptom clusters proposed by the *DSM-IV*, and comparability to findings with *DSM-5*-defined clusters is unclear. The latest edition of the *DSM* now requires both active avoidance and negative cognitions/mood, the latter often referred to as emotional numbing. One method of studying PTSD symptoms in the context of an EMA study was separating symptoms conceptualized as dysphoric from other symptoms related to the PTSD construct, such as intrusions, avoidance, and hyperarousal ([Kaysen et al., 2014](#); [Simms et al., 2002](#)). [Simpson et al. \(2012\)](#) propose these inconsistencies may also be reflections of the differing samples studied, such as gender of the participants, type of trauma exposure, and treatment-seeking status. Although prior research has found each symptom cluster to predict subsequent alcohol use, these results are limited by reasons outlined above, thus warranting additional research on this topic.

4.3. Moderator analyses

Several baseline variables were found to moderate the association between PTSD symptoms and alcohol-related variables. These studies generally examined moderation of the within-subject association between PTSD symptoms and alcohol-related variables. Variables found to moderate the association between PTSD symptoms and alcohol use in the theoretically predicted direction were: coping motives and enhancement motives ([Simpson et al., 2014](#)), AUD diagnosis ([Cohn et al., 2014](#)), avoidance coping and self-efficacy ([Possemato et al., 2015](#)), and trait impulsivity ([Black et al., 2018](#)).

Examination of multilevel moderation in which the moderator variable is a level 1 (time-varying) variable becomes more complex in that the between- and within-cluster components of moderation need to be separated ([Preacher, Zhang, & Zyphur, 2016](#)). However, such analyses may help to elucidate the specific conditions that place an individual at risk for a bad outcome, and therefore may be of both theoretical and clinical interest.

4.4. Mediator analyses

Few studies have conducted mediation analyses, which require the use of multilevel mediation analysis that can examine mediation at a between- and/or within- level ([Preacher, Zhang, & Zyphur, 2011](#)). In a within-subject mediation analysis, [Cohn et al. \(2014\)](#) reported that negative affect mediated the association between PTSD symptoms and same-day alcohol use.

4.5. Theoretical integration

Given the relatively small number of studies with varying goals, it is difficult to derive strong theoretical conclusions. What is perhaps most clear is that the observed temporal associations between PTSD symptoms and alcohol use are consistent with both the self-medication hypothesis and the mutual maintenance model. Most importantly, several studies reported that PTSD symptoms predicted subsequent alcohol use/problems when controlling for prior drinking ([Gaher et al., 2014](#); [Possemato et al., 2015](#); [Simpson et al., 2014](#)). However, there was less evidence that an alcohol use variable predicted subsequent PTSD symptoms when controlling for prior symptoms, although additional research is required to test this hypothesis.

As noted earlier, the self-medication hypothesis assumes that it is

the distress from symptoms that drives alcohol use. The results from [Cohn et al. \(2014\)](#) appear to provide support for this hypothesis in that negative affect (which is presumably related to distress) mediated the association between PTSD symptoms and same-day alcohol use. Further research needs to be conducted to determine whether those symptoms which elicit the most distress are most strongly associated with alcohol use. Moreover, few studies have directly tested predictions from social-cognitive theory, with only one study testing self-efficacy to avoid drinking as a moderator variable.

A further broad theoretical consideration is that the findings from between-subject associations do not always mirror those from within-subject associations (e.g., [Campbell et al., 2017](#)). This is not surprising given that associations occurring at one level of analysis cannot be inferred from associations observed at a higher, aggregate, level of analysis ([Gelman, Shor, Bafumi, & Park, 2007](#); [Robinson, 1950](#)). Ultimately, theories will need to be sufficiently elaborate to make predictions both at the between-subjects level (i.e., explaining associations between aggregated measures of PTSD and alcohol use), as well as at the within-subjects level. It is likely that as more nuanced descriptions of within-person associations between PTSD and alcohol use continue to be developed through use of EMA, behavioral theories will need to be adapted to accommodate the new findings.

4.6. Clinical implications

Interventions are needed for individuals to better cope with PTSD symptoms ([Kaysen et al., 2014](#); [Possemato et al., 2015](#); [Simpson et al., 2012](#)). With a sample of veterans with PTSD, [Possemato et al. \(2015\)](#) found that avoidance coping (i.e., keeping away from people, substance use) was a risk factor for reliance on alcohol while self-efficacy served as a protective factor. Increasing one's self-efficacy to resist drinking may lead to greater treatment success. Incorporating treatments, such as Motivational Interviewing (MI), which emphasizes the client's skills and strengths, can improve one's self-efficacy and ability to remain abstinent from drinking ([Possemato et al., 2015](#)). Coping strategies are useful not only for same-day PTSD exacerbations, but also when PTSD symptoms are increased the following day ([Simpson et al., 2014](#)).

Though reducing alcohol intake is key in treating comorbid PTSD and alcohol problems, such as an AUD, it may not be enough. Several studies found that PTSD symptom severity is more closely associated with alcohol-related problems than with alcohol use ([Gaher et al., 2014](#); [Hruska et al., 2017](#)). This is clinically relevant in that an individual may still experience alcohol-related consequences (i.e. negative cognitions about self), even after reducing their alcohol consumption ([Hruska et al., 2017](#)).

Cognitive biases, such as exhibiting greater attention to trauma- or negative-related stimuli, are often seen in individuals with PTSD, which may affect the accurate appraisal of alcohol-related problems in their life ([Wilson et al., 2017](#)). This tendency to overestimate the impact of alcohol on their life problems may interfere with treatment effectiveness, particularly with achieving behavior change goals ([Wilson et al., 2017](#)). PTSD treatments, such as cognitive processing therapy (CPT), utilize both cognitive and behavioral techniques to address biases such as this.

A discussion of clinical implications would be incomplete without acknowledging the debate on treating comorbid PTSD and substance use disorders, including alcohol. Currently, there is no "gold standard" treatment plan for individuals with both diagnoses ([Berenz & Coffey, 2012](#)). To date, research has been done on treating PTSD and SUD independently ([Foa et al., 2013](#)), enhancing PTSD treatments to address SUD ([McCarthy & Petrakis, 2011](#)), enhancing SUD treatments to address PTSD ([Mills et al., 2012](#)), and integrating treatments that address both disorders ([Najavits, 2002](#)). Regardless of the treatment course, attaining emotion regulation seems to be key both for PTSD and for alcohol use.

4.7. Limitations

This narrative review has several limitations. First, it involves review of a relatively small sample of studies that met the inclusion criteria. Second, regarding the analyses of moderation, different researchers have examined different moderator variables making it difficult to draw any strong conclusions. However, one point of our review was to highlight methods being used in EMA research to better understand the PTSD-alcohol use relationship. Third, few studies have examined mediation, which limited our discussion on that topic. Last, as noted above, studies have generally used symptom clusters proposed by the *DSM-IV*, and so the generalizability of these findings to the current diagnostic criteria of the *DSM-5* remains unclear.

4.8. Future research

Further research should examine predictors of assessment compliance to include both person-level and moment-level predictors. In these analyses, missing data can be modeled as an outcome variable. One can examine whether compliance can be predicted from contextual factors (e.g., whether compliance is reduced after episodes of heavy drinking). [Kaysen et al. \(2014\)](#) reported significant variability in reported PTSD symptom severity and alcohol use, and concluded this variability shows participants generally continued to report their symptoms even when they were more severe or after drinking. Nonetheless, a more formal analysis of predictors of compliance may be useful.

At a more methodological level, missing data can reduce power, and more problematically, missing data can potentially lead to biased parameter estimates from multilevel models if predictors of missingness are not included in analyses (see [Black et al., 2018](#), for an example of how this was handled). Another procedure that can potentially yield biased parameter estimates in analyses of multilevel data is the use of lagged dependent variables in prospective analyses ([Allison, 2015](#)). Researchers should be aware that use of lagged dependent variables can reduce the magnitude of the parameter estimate of a focal predictor variable, known as Nickell's bias ([Kripfganz, 2016](#)). Research using multilevel analyses, including multilevel mediation and moderation, should also take care to minimize biases due small cluster sizes when using analytic approaches that do not model measurement error ([Preacher et al., 2011](#); [Preacher et al., 2016](#)).

Future studies using larger samples may also benefit from emerging methodologies, such as machine learning, to examine prediction of short-term outcomes in individuals with PTSD and alcohol use ([Torous et al., 2018](#)). For example, it may be possible to build a predictive model to identify when individuals are at risk for bad outcomes, such as experiencing a heavy drinking episode or elevated PTSD symptoms. In such models, interactions between predictor variables may be important ([Rosellini, 2018](#)), which underscores the importance of further analysis of moderator variables. If real-time short-term prediction of outcomes is feasible, ecological momentary interventions (EMI) could be administered on mobile device to intervene "just-in-time" to prevent a bad outcome. Mobile health interventions have already been designed for individuals with either PTSD ([Kuhn et al., 2014](#)) or AUD ([Gustafson et al., 2011](#)), and components of MI, CPT, and other treatments can be administered remotely (e.g. CPT Coach and PE Coach mobile applications). Ultimately, combining EMA data with information from other digital data ([Dagum, 2018](#)) may lead to more personalized and effective treatments for dually diagnosed individuals.

Declaration of Competing Interest

All authors declare no conflicts of interest.

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