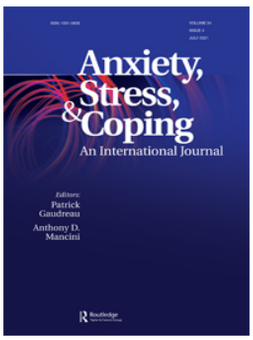

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ABSTRACT

Background: The stress-to-disease association has been well-accepted for some time. However, the understanding of *how* stress exposure contributes to psychological disease progression remains unclear.

Objective: To test the real-time impact of variable stress exposure on risk-related clinical phenomena and affective disease progression in a high-risk sample of active-duty firefighters.

Methods: Participants completed weekly diaries reporting stressful event exposure, affect, sleep, and risk-related and healthy behaviors over six-months and were evaluated for lifetime and current psychiatric disease using clinical interviews before and after the sampling period.

Results: Stress exposure impacted clinical phenomena in differing ways. Major personal events and day-to-day hassles predicted health-impairing shifts in sleep and behavior that were associated with increases in symptoms and psychological distress over the 6-month period. In contrast, highly aversive incidents predicted greater adaptive behaviors that were uniquely predictive of symptom decreases over the six-month period.

Conclusion: These findings shed new light on stress-to-disease processes, demonstrating how variable stress exposure influences critical shifts in behavior and sleep, contributing to psychological adjustment of firefighters over time. These data suggest practical ways to monitor risk in high-risk samples (e.g., monitoring sleep latency) and offer avenues for further explication of disease processes in real time.

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Stress exposure; risk behavior; affect; sleep; psychopathology

Although the association between stressful life experiences, whether chronic or acute, and psychiatric symptoms is well-established, the precise pathway remains largely unclear. Indeed, across the literature, there is broad consensus that stressful life events tax psychological resources and, in *some* individuals, stressful events trigger symptom onset or exacerbation. However, because the precise mechanism underlying this process remains murky, the development of effective intervention and assessment tools has been limited (Cohen et al., 2007; Kraemer et al., 2001). In the current study, we sought to begin to clarify these processes in a high-risk sample of active-duty firefighters assessed longitudinally over six months. We tested a path by which stress exposure impacted clinical domains central to psychological health and disease risk including sleep, affect, risk-related maladaptive and healthy behaviors (e.g., substance use, exercise, binge-eating, social

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support activities, relaxation). Then we tested how the accumulation of these clinical phenomena impact the longer-term development of disease. The primary goal was to begin to clarify the dynamic process of disease progression to better inform risk assessment and models of stress-related psychopathology.

Stress to Disease Pathways

Decades of rigorous psychological research has consistently supported a diathesis-stress framework linking stressful life experiences, both chronic and acute, to affective disorders (including mood, anxiety, and stress disorders; Hammen, 2016). Although most individuals exposed to highly stressful events maintain high levels of functioning resulting in resilient outcomes, a minority demonstrate significant disruptions in functioning and lasting psychological symptoms that could be diagnosed as affective disease (Bonanno, 2004). This pattern is present even in high-risk samples who experience a combination of chronic high stress punctuated by highly aversive acute incidents, (e.g., military personnel, emergency responders, and civilians in conflict zones: Feder et al., 2016; Hobfoll et al., 2011). However, much less is known about which unique and clinically relevant factors drive symptom change over time, leading *only some* individuals on a path to disease. Although research has identified an array of factors that broadly contribute to disease risk in stressed samples (e.g., gender, age, trauma exposure, genetic variation, socio-economic status, and social support; Bonanno et al., 2010; Hammen, 2016; Monroe et al., 2019), these variables are often static and might not shed direct light on the dynamic processes that drive disease progression.

There is a broad theoretical literature suggesting that nuance around stress exposure is needed and that the processes relating to disease onset are highly complex. For example, *stress sensitization* theories (Monroe et al., 2019) posit that early stress exposure and repeated stressful events can sensitize individuals to stressful circumstances through endocrine and behavioral channels, dynamically increasing risk so that even less significant stressors begin to initiate symptoms with each subsequent exposure. In contrast, *stress generation* models demonstrate that across affective disorders (e.g., depression, anxiety, stress disorders; Conway et al., 2012; Hammen, 2016) there is objective evidence of *increased* frequency of stressful events, even in an individual currently without symptoms. Hence, both models suggest a dynamic interplay between stress exposure and disease but have not yet specified how stress influences symptom onset or exacerbation.

In the case of individuals in heightened risk environments, where both chronic stress and acute aversive incidents are common, such questions are of considerable clinical importance. For example, emergency responders often face daily stress exposure from routine 911 calls (e.g., for chronically sick community members) or the stress of daily living in their personal lives (e.g., financial challenges, parenting stress) in combination with highly aversive events both at work (e.g., multiple fatalities in house fire or car crash) and home (e.g., loss, divorce). How these overlapping contexts impact an individual's psychological resources and their potential pathway to disease has not yet been well-captured. In particular, there is a marked absence of research demonstrating how micro or moment-level shifts in key health-related phenomena, such as sleep, affect, and behavior can be impacted by stress exposure occurring over time. Indeed, although there is broad support for stress-related disruptions in circadian, endocrine, affective and behavioral processes that could underlie the stress-disease pathway, research rarely investigates these processes dynamically, nor evaluates multiple behaviors or risk-related phenomena simultaneously. For example, considerable evidence supports the interplay of stress and sleep inefficiency in negative affective processes, including evidence that sleep disruption may undermine well-being in high-risk populations such as firefighters (e.g., Carey et al., 2011). Research generally supports an association between both reduced sleep quantity and longer sleep onset latency (SOL; time to fall asleep) and symptoms of affective disease (e.g., Biddle et al., 2019). However, how sleep disruptions relate to *specific* stress exposure, and to other risk phenomena has not been demonstrated, thereby limiting how interventions or assessment tools could be developed.

Another key pathway is via the emotionally evocative elements of stress exposure. Intense emotions may function as a transdiagnostic catalyst for risk-related phenomena. For example, research has demonstrated stress-linked associations to consumptive behaviors, driven by change in affect (e.g., Tryon et al., 2013). Other research has linked stress-related shifts in affect to increased risk-taking (e.g., Ceccato et al., 2016), as well as a range of risk-increasing behaviors including substance use, gambling, binge eating or non-suicidal self-injury (e.g., Brendahan et al., 2017; Coifman et al., 2012). In contrast, there is also a growing but separate literature that has demonstrated the protective elements of intense emotion in adaptive or healthy behaviors, such as exercise or seeking support in highly stressed populations (e.g., Phillips et al., 2012). Indeed, there is compelling evidence that healthy behaviors are predicted by shifts in positive emotion, even among patient samples (Nylocks et al., 2019).

Affective shifts (increasing negative and/or decreasing positive emotions), risk-related behaviors, and sleep disruptions are all transdiagnostic phenomena, and represent core symptoms across mood, anxiety, and stress disorders (American Psychiatric Association [APA], 2013). Indeed, maladaptive risk-related behaviors that emerge in response to heightened distress or negative emotion are clearly implicated in affective disease, as evidenced by the high co-occurrence of affective, substance, and eating disorders (Kessler et al., 2005). In sum, there is compelling evidence to suggest that stress exposure can be associated with the onset or progression of key transdiagnostic symptoms but this dynamic process has not yet been demonstrated in research. Capturing the process of disease onset is particularly important for high-risk populations experiencing multiple dynamic stressors so that careful monitoring and early identification of individuals at higher risk can be most effective.

Current Investigation

The primary goal of this investigation was to test the real-time impact of stress exposure on risk-related clinical phenomena, including behaviors, affect, and sleep in a high-risk sample of active-duty firefighters. Prior research on all key variables has clearly linked stress to risk-related behaviors, sleep, and disease. However, the primary aim of this investigation was to begin to disentangle micro (or momentary) influences from the broader (or macro) level processes in order to shed light on disease progression, thereby informing intervention development and improving risk assessment. Stress, behaviors, affect and sleep were assessed weekly via electronic diaries over a six-month period, and participants completed a thorough diagnostic evaluation at the start and conclusion (total of two time points of data) of the same period. To account for within – and between-person variability, we applied multi-level models to test specific varieties of stressful experience (minor hassles, major personal events, and major work-related incidents) in relation to affect, risk-related behavior and sleep in real time. Then, we applied conventional longitudinal models to test how aggregated estimates of sleep, affect, and risk-related behavior impacted symptom or distress change over the entire study period,[1] with stress exposure also considered. Finally, other known risk factors including psychiatric and treatment history, sex, and age, as well as factors specific to the work of an active duty firefighter (e.g., hours worked weekly, rank) were considered as they could also influence all key variables.

We broadly hypothesized that stress would impact all key clinical variables (sleep, risk-related behaviors, and affect) and that these key variables would impact psychological symptoms and distress. However, we anticipated that the path by which this would manifest would be dependent on time scale. Specifically, stress exposure would impact sleep, affect, and behavior in real time (estimated weekly), and that, overall, this impact would predict symptom or distress change over months. We took this approach for several reasons. First, each of our key variables (sleep, risk-related behaviors, and affect) share variance with the others. Indeed, there is a large literature demonstrating the ways in which negative and positive affect impact and are impacted by sleep, as well as impact and are impacted by risk and healthy behaviors (e.g., Fucito et al., 2018; Konjarski et al., 2018; Quilty et al., 2017). Rather than presuming to be able to predict how these relationships

manifest, we instead opted to rigorously test for unique impacts of weekly stress exposure on these variables by testing models that were inclusive of other factors. For example, we aimed to explore if variable stress exposure impacts sleep, even when considering shared variance with affect and behavior. Indeed, prior research attempting to parse stress exposure has been limited and it is rare to find investigations testing the impact of stress on more than one behavioral or symptom dimension at a time. Moreover, we were both exclusive and inclusive in our longitudinal modeling to more effectively test which factors are relevant to disease progression and to identify which factors might be the most meaningful targets for intervention or assessment.

Method

Participants

Participants ($n = 72$) were adults with mean age 37.67 ($SD = 8.31$), mostly male (94%), White/Caucasian (86%), and non-Hispanic (93%) active-duty firefighters. Participants had high school (50%) or some college education (50%) and were experienced emergency responders (mean years = 12.38, $SD = 7.96$). Seventy-five percent held the rank of Firefighter,[2] and 67% of the sample also served as paramedics, which meant that they were the first responders on scene from their respective units. In this district, firefighters are responsive to all 911 calls. Data provided by the department indicated that during 2018, the year in which data collection occurred, fire units responded to 47,154 calls; of those, 7.27% were fires, the majority of responses involved rescue or medical emergency (90.1%) including responses to car crashes, violence, and drug overdose in the community. False alarms accounted for 2.6% of calls.

Notably, sixty-four percent of participants worked an additional job, and for 28% of the sample, this was at another fire department or paramedic service. This additional work increased average work hours per week as depicted by the weekly mean hours ($M = 53.35$, $SD = 12.08$) reported across the six-month reporting period. Typically, firefighters in this jurisdiction work two to three 24-hour shifts with 48-hours of rest in between, weekly.

Procedure

Active-duty firefighters from an urban fire district were recruited as part of a larger project to understand emotion processes and psychological risk in this population. Individuals working as firefighters were offered the opportunity to participate during routine training sessions when they were pulled off active duty, *during* shifts, for activities at the department training facility. Eligible individuals were told this was research about "firefighter resilience" and informed of the study activities via flyer and announcements at regular meetings. All interested individuals were brought to a private area at the training facility for participation. Following written informed consent, participants completed questionnaires, a diagnostic interview, and emotion-related tasks not relevant to this investigation. At the conclusion of the session, participants were trained to complete weekly diaries that commenced the following Monday and were sent one time weekly, via email, to participants over the next six months. Following the completion of six months of diaries, participants were contacted by the study team and completed a second diagnostic interview by phone. Participants were compensated $25 for the initial session and were entered into a lottery for three, $500 Amazon gift cards at the end of data collection. This investigation was approved by the Kent State University Institutional Review Board, and all participants provided written informed consent prior to the start of data collection.

Measures

Diagnostic interviews and treatment history. Participants were interviewed in-person at the initial session (Time 1) and by phone at the final session, six-months later (Time 2), using the Structured

Clinical Interview for the Diagnosis of DSM-5 Disorders (SCID-5: First et al., 2015) by advanced doctoral candidates in clinical psychology. Interviewers were trained and supervised by a licensed clinical psychologist (the first author). Videos were used to assess reliability at both the symptom and diagnostic level. All interviewers achieved reliability on SCID-5 modules by scoring 5 randomly selected videos: average agreement at the symptom level was $\kappa = 0.82$ (range: .77–.85). Diagnostic assessments included all past and current psychopathology, and each participant was assigned a summary score of past diagnoses that was the sum of the number of disorders for which they met criteria over their lifetime. This was used as a covariate in all analyses.

In addition, given the very considerable literature demonstrating stress exposure impacts all affective disorders including depression and posttraumatic stress disorder (PTSD; Hammen, 2016), we applied a rigorous index of current psychopathology by merging current, non-redundant symptoms of Major Depressive Disorder (MDD) and PTSD assigned by a clinician during the SCID as a continuous index of current symptoms, at the initial session ($M = 1.41$, $SD = 1.88$ [range: 0–8]) and again at the study conclusion six months later ($M = 0.91$, $SD = 1.96$ [range: 0–11]), with mean symptom change .67 ($SD = 2.77$). This transdiagnostic indicator of symptoms, using a clinician-administered SCID, was developed previously for use in other high-risk populations (e.g., Bonanno et al., 2007; Coifman & Bonanno, 2010) and is a reliable estimate of clinically meaningful symptom change. To derive these symptom scores, SCID-5 procedures were adapted so that *all* participants were administered *all* symptom items of both modules, MDD and PTSD, for the past month. The final index of symptoms was used as one of two primary dependent variables in the longitudinal analysis, and the initial index of symptoms was included as a covariate in all analyses. Twenty-seven participants were not available to complete diagnostic interviews at follow-up. Thus, the longitudinal analysis using the SCID-5 symptom index was limited to a subset of 43 participants.[3]

In general, the sample had rates of psychopathology consistent with other emergency responder populations (Petrie et al., 2018) and the general population (Kessler et al., 2012). Approximately 22% of the sample met diagnostic criteria for at least one current psychiatric disorder at the initial session, and 44.3% had a lifetime history of reaching the diagnostic threshold for at least one disorder (mood, anxiety, stress, attention, eating, and substance use disorders). Importantly, *all* participants had considerable history of trauma exposure. During the SCID-5 PTSD screener, participants reported exposure to a mean of 6.01 ($SD = 2.24$) PTSD-qualifying event categories. Although all individuals reported PTSD qualifying event exposure professionally, 83% reported personal exposure as well. Finally, 17% of the sample reported some prior or current treatment with psychiatric medication and/or psychotherapy.

Psychological distress. Participants completed the Depression, Anxiety, and Hostility sub-scales from the Symptom Check List-90-R (SCL-90; Derogatis, 1983) at both the initial and follow-up data collection as an index of psychological distress. Participants rated how much they had been "distressed or bothered" by 29 psychological symptoms (e.g., headaches, crying easily, feeling irritated) "during the past seven days" on a 5-point Likert scale (0 = not at all; 4 = extremely). This scale has been used frequently in high-stress samples (e.g., Coifman et al., 2007) to estimate psychological distress. In our sample, the scale exhibited excellent internal consistency and scores within the low-moderate range: initial ratings: $M = 0.29$, $SD = .29$, $\alpha = .89$, follow-up: $M = 0.33$, $SD = .42$, $\alpha = .94$. Ten participants were not able to provide follow-up ratings, thus, longitudinal analysis using the SCL-90 distress index was limited to a subset of 62 participants.

Experience sampling diary. Participants were trained in the completion of the weekly experience sampling diary and practiced before leaving to ensure understanding and improve compliance. The diary was emailed to participants each Monday during the six-month participation period via a secure survey portal, *Qualtrics*. Given variable shift schedules (2–3, 24-hour shifts weekly, with 48 h off in-between) the Monday-weekly email captured expected variability in terms of on-work versus off-work days. The maximum possible number of diaries was twenty-seven. Two participants completed only one diary entry each and were dropped from analyses. The mean number of diaries completed by the remaining participants ($n = 70$) was 19.41 (SD = 6.01; range: 5–27). Overall

compliance was acceptable at 72% and our micro-level analysis included approximately 1,330 diary signals. Each diary prompted the report of current affect, sleep, risk-related behaviors enacted in the previous 24 h, and stress exposure and the estimated number of hours worked over the previous 7 days.

Affect. At each diary signal, participants reported their *current* affective state by rating eight negative (anger, boredom, disgust, distress, fear, guilt, sadness, shame) and six positive (affection, amusement, contentment, happiness, interest, relief) emotion words on a 1 (none at all) to 7 (extremely) Likert scale. Ratings were aggregated into negative and positive affect scores, that were each parsed into a person-mean, reflecting their average affect across the whole diary sampling period of six months, as well as into person-centered scores, reflecting state-level deviations from their own mean (Bolger & Laurenceau, 2013). Reliability was assessed following recommendations (Cranford et al., 2006), and between – (R_{kf}) and within-person reliability (R_c) for both negative affect (R_{KF} = 0.99; R_C = 0.61) and positive affect (R_{KF} = 0.99; R_C = 0.74), were good.

Sleep. In each diary, participants reported the time at which they went to bed the night before, the delay in minutes before falling asleep, and the time at which they were awake. From this data we derived a score in minutes for both sleep onset latency (SOL) and sleep quantity each week. Mean sleep quantity of 394 min (6.56 h; *SD* = 62.56), and mean SOL of 44.03 min (*SD* = 28.81) were largely consistent with other research examining sleep in firefighters (Carey et al., 2011) and in US adults (Grandner & Kripke, 2004) although latency estimates here are longer than some (Ram et al., 2010).

Risk-Related Behaviors. After reporting on sleep, participants indicated if they had engaged in risk-related behaviors over the past 24 h. Response options were "yes," "no but I had a strong urge," or "no." Behaviors were presented randomly but were parsed into two scales consistent with their prior association with psychological symptoms. Strong urges and yes responses were aggregated based on prior research indicating they are driven by the same underlying processes (Hofmann et al., 2012) particularly for high risk behaviors[4] (Johnson et al., 2013; Zaki et al., 2013). Maladaptive risk-related behaviors included substance use, risky sex, overspending, misuse of medication, binge eating, social avoidance, self-injury, and other reckless behaviors (e.g., gambling/reckless driving). Adaptive healthy behaviors included exercise, relaxation activities, hobbies, spending time with a supportive other, healthy eating, and engaging in group social activities. During diary training, each participant was instructed on the definition and given examples of each behavior prior to commencing the diary and summary definitions were presented during the diary at each signal. Endorsement of any behavior was summed along the two dimensions of maladaptive or healthy behaviors so that each participant had a score of 0–7 for maladaptive behaviors and 0–6 for healthy behaviors each week. Although behavioral data can have overdispersion because of excess zeros when behaviors are infrequent or uncommon, we selected behaviors that are common in adults and in this particular population (e.g., Carey et al., 2011; Nylocks et al., 2019). As such, when we examined the distribution of the *summed* scores, there was a normal distribution, little to no skew, nor evidence of zero-inflation or dispersion. Finally, rates of healthy and maladaptive behaviors were consistent with expectations, 88% of diary reports included mention of at least one maladaptive behavior and 100% of diary reports included mention of at least one healthy behavior. The details on the frequency of each individual behavior in the sample and comparisons to other samples are provided in detail in the supplemental materials (Table S2, pages 1–3).

Stress Exposure. At each diary assessment, participants were asked to indicate "yes" or "no" to each event on a list of fifty-two events that had occurred in the previous week. Events were presented in random order at each diary, and endorsements of events were summed based on the following groupings so that each participant had three stress scores for each weekly diary:

Daily hassles – or – major personal events. These were indexed with the weekly life event survey (Lalande & Bonanno, 2011) and included highly aversive personal events (e.g., loss, assault, divorce) as well as daily hassles (e.g., changes in responsibility, interpersonal conflict, illness, financial stress).

Work aversive incidents. These referred to major events occurring in the context of duties as a firefighter and were indexed with a tool designed to index highly aversive incidents specific to fire-emergency workers (e.g., death of a child, multiple fatalities, death of a co-worker, serious risk to self, etc.; Monnier et al., 2002).

Mean reports of daily hassles ($M = 0.32$, $SD = 0.36$), major personal events ($M = 0.33$, $SD = 0.40$), and work aversive incidents ($M = 0.35$, $SD = 0.40$) suggested that the frequency of all types of stress exposure were relatively similar across the sampling period.

Data Analytic Strategy

Our primary aim was to examine the direct effects of stress exposure on variability in sleep and behaviors in real-time throughout the sampling period, as well as the broader impact of sleep and risk-related behaviors in symptom change from the beginning to the end of the six-month study period. Given the considerable prior research suggesting overlapping variance among all key variables, we opted not to test for specific moderation or mediation effects given our sample size and estimates of power. Specifically, recent simulations suggested we would not have adequate power to test moderation effects but would be adequately powered to test multiple direct effects (Scherbaum & Ferreter, 2009). Hence, we focused on identifying direct effects, as well as evaluating their relative contributions to symptom change over time. Notably, because affect reports are tightly intertwined with all key variables in a likely complex and dynamic system, we were careful to covary affect in all analyses of sleep and risk-related behaviors but did not test it as a specific outcome on its own. Finally, we considered treatment history (current and past), age, sex, hours worked, and rank in the department as covariates in all analyses given their potential impact on all key variables.

Micro-level processes: Testing the momentary association between stress exposure, sleep, and behavior. To examine how weekly stress exposure impacted sleep variables and risk-related behaviors, we used a linear mixed model framework to better manage within-person and between-person variability across all key variables. To covary affect in our analyses, we parsed emotional experience (negative and positive affect) into both moment-level or "state" deviations from an individual's mean, as well as person-level means reflective of trait affective tendencies. This approach allows us to evaluate how momentary shifts in negative or positive affect were relevant to reports of risk-related behaviors or sleep, as compared to trait-like tendencies. We also included each of the three weekly stress exposure scores (minor hassles, major personal events, work aversive incidents) and report of weekly hours worked (given the likelihood that more work hours could influence all types of stress exposure in meaningful ways). At the person-level, we included the initial index of current symptoms (depression and PTSD, per the SCID) and the index of past psychopathology to account for the possibility of stress generation (Hammen, 2016) as well as established associations between symptoms, maladaptive behaviors, and sleep disruption. In total, we planned to run four models applying the Proc Mixed procedure (SAS, 1992), predicting the following four diary-level outcomes: SOL, sleep quantity, report of maladaptive risk behaviors, and report of adaptive healthy behaviors. After each model, we did one final test to confirm that the other outcome variables did not better account for any found associations (e.g., covarying risk-related behaviors when evaluating sleep outcomes). We employed an autoregressive error structure and degrees of freedom were restricted to the number of participants (Bolger & Laurenceau, 2013). All equations and details are in the supplemental materials (pages S6-12).

Macro-level processes: Testing the role of sleep, affect, and risk-related behaviors in symptom development over time. To test the broader impact of disruptions in sleep, affect and risk-related behaviors in symptom development and changes in psychological distress over the six-month study period, we applied ordinary least squares (OLS) regression models – a dominant tool in longitudinal assessments of change. In each model, we covaried the SCID symptom index from the initial assessment as well as the index of past psychopathology. The dependent variable was either symptoms assessed at the final diagnostic interview or reports of psychological distress. We planned to run a total of two

multi-step OLS regression models for each dependent variable, focusing on pathways relating to sleep disruption and risk-behaviors, while also considering affect. In each model, we entered the key variables in separate steps (SOL and sleep quantity; maladaptive risk behaviors and adaptive healthy behaviors) to evaluate their relative influence on the dependent variable. Each was included as person-estimate (an aggregate from across the sampling period) per recommendations (Foster-Johnson & Kromrey, 2018). Finally, based on the results of the initial models, we ran one fully inclusive model to test the incremental influence of each factor over the others (i.e., sleep disruption vs. risk behaviors) on symptom development and then on distress. As before, we covaried affect (mean negative and positive affect) as well as sex, treatment history, rank, and hours worked. Finally, we reran each model, covarying estimates of stress exposure across the six-month sampling period (person-mean levels for each of the three exposure types) so as to test that symptom change was due to variability in sleep, behaviors, and affect, rather than the direct effects of stress exposure.

Results

Preliminary Analysis

We first examined associations between key variables (see Table S1 in supplemental materials). As expected, there were significant associations between mean negative affect and stress exposure, including minor hassles and major personal events but not work aversive incidents, as well as associations with SOL, maladaptive risk-related behavior, and initial symptoms and distress. Stress exposure variables were generally positively associated with each other and with mean hours worked. Sleep variables were associated with current symptoms (e.g., higher symptoms with shorter sleep quantity and longer SOL) at both time points and past psychopathology, and SOL with distress. Maladaptive risk-related behaviors were also associated with current symptoms (Time 1), Distress (Time 1 and 2) and past psychopathology. Adaptive healthy behaviors and mean positive affect were significantly associated with each other but were not related to any other variables. We also confirmed that individual maladaptive risk-related behaviors and adaptive healthy behaviors were associated within each category. Generally, we found significant positive associations within each category (*r*s = .33-.57) and only few significant associations cross-category (see Table S1 in the supplemental materials).

Micro-level Analyses: Stress and sleep across 6 months of weekly sampling

To examine the effect of stress exposure on sleep, we ran separate mixed models predicting diary reports of SOL and sleep quantity. The fixed effects are summarized in Table 1 (equations for each model are described in the supplemental materials, pages S6-12).

Sleep onset latency. Our results indicated that major personal events significantly predicted longer SOL, $B = 8.66$, $p = .009$, such that one additional major personal event was associated with approximately nine minutes delay in sleep onset. No other stress variables nor affect variables were significant predictors. However, past psychopathology also emerged as a significant predictor, $B = 5.62$, $p = .043$, such that each additional past diagnosis was associated with approximately six minutes delay in sleep onset. Current symptoms and hours worked did not reach significance. We reran this model including maladaptive risk-related and adaptive healthy behaviors, and the effects for major personal events predicting SOL were very similar, $B = 9.13$, $p = .007$, plus there was an additional effect of adaptive healthy behaviors, $B = -3.63$, $p = .02$, such that for every additional healthy behavior reported, SOL *decreased* nearly 4 min.

Sleep quantity. Our results indicated that minor hassles significantly predicted shorter sleep duration, $B = 18.34$, $p = .004$, such that for every additional minor hassle, sleep quantity decreased by about 18 min. There was also a marginal effect of initial symptoms, $B = -7.96$, $p = .056$, such that each additional symptom identified during the initial diagnostic interview was associated with

Table 1. Micro-level analyses of stress exposure to weekly sleep variables.

Fixed Effects	Estimate	SE	*p*	95% C.I.
Weekly Sleep Quantity				
Intercept	431.18	29.75	<.0001	371.7,490.6
Work Aversive Incident Exposure	−6.85	4.22	0.109	−15.26,1.56
Minor Hassles	−18.34	6.17	0.004	−30.64,−6.03
Major Personal Events	−3.43	6.03	0.571	−15.45,8.60
Hours Worked	−0.11	0.15	0.469	−0.40,0.19
Current Person-centered positive affect	0.05	6.56	0.994	−13.04,13.14
Mean positive affect	−5.23	7.94	0.513	−21.07,10.62
Current Person-centered negative affect	−8.80	13.55	0.518	−35.85,18.24
Mean negative affect	4.55	17.86	0.800	−31.09,40.19
Initial Symptoms	−7.96	4.10	0.056	−16.14,0.22
Past Psychopathology	−3.58	7.11	0.617	−17.77,10.62
Time (between diary responses)	0.20	0.58	0.729	−0.95,1.35
Weekly Sleep Onset Latency				
Intercept	19.33	13.35	0.153	−7.4,46.0
Work Aversive Incident Exposure	2.08	2.29	0.368	−2.5,6.6
Minor Hassles	1.62	3.34	0.630	−5.1,8.3
Major Personal Events	8.66	3.22	0.009	2.2,15.1
Hours Worked	−0.05	0.08	0.550	−0.2,0.1
Current Person-centered positive affect	2.65	2.71	0.331	−2.8,8.1
Mean positive affect	0.58	3.46	0.868	−6.3,7.5
Current Person-centered negative affect	3.04	6.55	0.643	−10.0,16.1
Mean negative affect	7.97	7.71	0.305	−7.4,23.4
Initial Symptoms	2.47	1.70	0.151	−0.9,5.9
Past Psychopathology	5.62	2.72	0.043	0.2,11.1
Time (between diary responses)	0.38	0.31	0.223	−0.2,1.0

nearly 8 min of sleep quantity loss. No other stress variables, affect variables, hours worked, nor past psychopathology were significant predictors. As above, we reran the model covarying maladaptive risk-related and adaptive healthy behaviors and the effects were the same: minor hassles, $B = -19.49$, $p = .002$, and current symptoms, $B = -8.37$, $p = .043$. Each predicted a considerable decrease in sleep quantity. There were no other significant effects in this enhanced model.

Micro-level Analyses: Stress and risk-Related behaviors across 6 months of weekly sampling

As with the sleep analysis, we ran separate mixed models predicting diary reports of maladaptive risk-related behavior and adaptive healthy behavior. The fixed effects are summarized in Table 2 (equations for each model are described in the supplemental materials).

Maladaptive risk-related behaviors. Our results suggested that only minor hassles were positively associated with reports of maladaptive behaviors, $B = 0.089$, $p = .03$. No significant associations were observed for the other stress variables. In addition, mean levels of negative affect across the diary (reflecting trait levels) were positively associated with maladaptive behaviors, $B = 0.496$, $p = .001$. These relative effects suggested that, although an increase in one minor hassle increased the likelihood of maladaptive behavioral enactment by nearly 10%, a one unit increase in negative affect across the diary, increased this likelihood by nearly 50%. There were no other effects for affect, symptoms, past psychopathology, or hours worked. We reran the model controlling for the two sleep variables; the effects for minor hassles, $B = 0.085$, $p = .049$, and mean negative affect, $B = 0.486$, $p = .001$, remained the same. Further, there was an additional very small effect of sleep quantity, $B = -0.001$, $p = .039$, but no effect for SOL.

Adaptive healthy behaviors. Our results suggested that highly aversive incidents at work were positively associated with adaptive healthy behaviors, $B = 0.09$, $p = .029$, such that one additional report of a critical incident was associated with a 9% increase in the likelihood of engaging in adaptive behaviors. There were no other effects for stress exposure. In addition, hours worked also

Table 2. Micro-level analyses of stress exposure to weekly risk-related behavior variables

Fixed Effects	Estimate	SE	*p*	95% C.I.
Weekly Maladaptive Risk Behaviors				
Intercept	0.284	0.236	0.233	−0.19,0.76
Work Aversive Incident Exposure	−0.005	0.028	0.852	−0.06,0.05
Minor Hassles	0.089	0.041	0.033	0.01,0.17
Major Personal Events	0.03	0.041	0.429	−0.05,0.11
Hours Worked	−0.00	0.001	0.442	−0.00,0.00
Current Person-centered positive affect	0.007	0.039	0.969	−0.07,0.08
Mean positive affect	−0.061	0.065	0.351	−0.19,0.07
Current Person-centered negative affect	0.064	0.099	0.522	−0.13,0.26
Mean negative affect	0.496	0.144	0.001	0.21,0.78
Initial Symptoms	0.049	0.033	0.147	−0.02,0.12
Past Psychopathology	0.072	0.059	0.220	−0.04,0.19
Time (between diary responses)	−0.004	0.004	0.357	−0.01,0.01
Weekly Healthy Behaviors				
Intercept	1.526	0.407	0.000	0.71,2.34
Work Aversive Incident Exposure	0.090	0.040	0.029	0.01,0.17
Minor Hassles	0.016	0.058	0.791	−0.10,0.13
Major Personal Events	0.010	0.059	0.862	−0.11,0.13
Hours Worked	0.003	0.001	0.036	0.00,0.01
Current Person-centered positive affect	0.360	0.046	0.000	0.27,0.45
Mean positive affect	0.590	0.107	0.000	0.38,0.80
Current Person-centered negative affect	−0.563	0.137	0.000	−0.84,−0.29
Mean negative affect	0.024	0.239	0.921	−0.45,0.50
Initial Symptoms	−0.063	0.048	0.191	−0.16,0.03
Past Psychopathology	0.067	0.088	0.451	−0.11,0.24
Time (between diary responses)	−0.000	0.005	0.957	−0.01,0.01

increased the likelihood of adaptive healthy behaviors, $B = 0.003$, $p = .036$, although the effect was small. Importantly, positive affect was a strong predictor of adaptive healthy behaviors, including both momentary signal-level increases in positive affect, $B = 0.36$, $p < .001$, and mean levels of positive affect across the sampling period, $B = 0.59$, $p < .001$. In contrast, momentary increases in negative affect were negatively associated with adaptive healthy behaviors, $B = -0.56$, $p < .001$. There was no effect for mean levels of negative affect, symptoms, and past psychopathology. We reran this model covarying the two sleep variables and the findings remained the same, although the effects for both work aversive incidents, $B = 0.077$, $p = .063$, and hours worked, $B = 0.003$, $p = .081$, were now marginal. All positive and negative affect associations remained identical, and there were no effects for sleep variables.

The results from all micro-level analyses suggested specific effects for different types of stress exposure on sleep and behaviors, even when considering the overlapping influences of these variables with affect and each other. The next set of analyses, at the macro-level, tested the ways in which sleep, affect and maladaptive risk and adaptive healthy behaviors impacted symptom and distress development over months.

Macro-level Analyses: Sleep and disease progression over 6 months

We tested the role of SOL and sleep quantity in symptom or distress change from the six-month period between the initial diagnostic interview and the final diagnostic interview. The primary dependent variables were the continuous index of non-redundant symptoms extracted from the SCID-5 depression and PTSD modules and self-reported psychological distress. The final index of symptoms was skewed (skew = 3.65), so we used a square-root transformation in the regression analysis which made the index well-within conventions (skew = 1.53). In the initial step of the analyses, we controlled for initial symptoms (or distress) and past diagnosis of psychopathology, mean hours worked, age, sex, rank, and psychiatric treatment. However, hours worked, rank, and treatment did not enter meaningfully into the model and were dropped. In the next step, we entered mean

negative and positive affect.[5] In the third step we entered mean sleep quantity, and in the final step we entered mean SOL. A summary of the results is described below with all steps detailed in the supplemental materials (S13-16).

The results for SCID-5 symptoms suggested that shorter sleep quantity marginally, $\beta = -0.30$, $p = .079$, $sr^2 = .06$, and longer SOL significantly, $\beta = 0.40$, $p = .018$, $sr^2 = .11$, predicted increased symptoms six months later (Time 2), $F(8, 34) = 2.78$, $p = .018$. Although the effect was clearest for SOL, each variable contributed significant additional variance to the model, so that the final model predicted 40% of the variance in symptoms. When investigating the impact of sleep on psychological distress, there were no significant effects for either sleep quantity nor for sleep onset latency.

We reran the analysis including the stress exposure variables to test if stress exposure changed the effects of the sleep variables or if stress exposure had any direct association to symptom change or distress. There was no evidence of a direct stress exposure to symptom association, and the size of the effect of SOL, $\beta = 0.40$, $p = .023$, $sr^2 = .11$, and that of sleep quantity, $\beta = -0.29$, $p = .11$, $sr^2 = .05$, were similar. The effects for sleep were unchanged with stress included for reported distress.

Macro-level Analyses: Risk-related behaviors and disease progression over 6 months

We next tested the role of risk-related behaviors in symptom or distress change using the same structure for our OLS regression model. We removed the sleep variables and entered mean maladaptive risk behaviors in the third step and mean adaptive healthy behaviors in the final step. All steps of the model are in the supplemental materials (pages S13-16). Again, rank, treatment, and hours worked did not impact the models and were dropped. Overall, the results for SCID-5 symptoms at the final diagnostic interview suggested a significant positive association for maladaptive behaviors, $\beta = 0.38$, $p = .049$, $sr = .08$, and a significant negative association for adaptive healthy behaviors, $\beta = -0.40$, $p = .024$, $sr^2 = .11$, $F(8, 34) = 2.31$, $p = .043$, predicting 35% of the variance in symptoms at the end of the study period. The results for reported psychological distress at 6 months, indicated a significant positive association between maladaptive behaviors, $\beta = 0.43$, $p < .001$, $sr^2 = .19$, $F(8, 53) = 8.16$, $p < .001$, with the full model predicting 55% of the variance in distress at the end of the study period. There was no association between adaptive behavior and reported psychological distress.

We reran the analyses including the stress exposure variables to test if stress exposure diminished the effects of risk-related behaviors or had any direct association to symptom or distress change. As with the sleep analysis, there was no evidence of a direct stress exposure-to-symptom association. In addition, the association of maladaptive risk-related behaviors, $\beta = 0.35$, $p = .08$, $sr^2 = .07$, and healthy behaviors, $\beta = -0.41$, $p = .029$, $sr^2 = .11$, to final symptoms were similar. This was very consistent in the analysis for reported psychological distress: stress variables did not enter significantly into the overall model, and the effects for maladaptive behaviors were nearly identical, $\beta = 0.54$, $p < .001$, $sr^2 = .16$.

Macro-level Analyses: Incremental effects of sleep, affect, risk-related behaviors, and stress on disease progression over 6 months

Finally, we ran one additional model for each dependent variable in which we included all key variables, sleep, affect, risk-related and healthy behaviors, and maintained the covariates from the prior macro-level analyses (i.e., initial symptoms, past psychopathology, age, sex). The results were consistent with the prior models and predicted between 49-58% of the total variance in symptoms or distress at the final diagnostic interview. Specifically, the largest impact on longitudinal symptoms was from SOL, $\beta = 0.37$, $p = .02$, $sr^2 = .10$, then adaptive healthy behaviors, $\beta = -0.31$, $p = .07$, $sr^2 = .06$. Maladaptive behaviors had a marginal effect, $\beta = .30$, $p = .095$, $sr^2 = .05$, and sleep quantity, $\beta = -.18$, $p = .29$, $sr^2 = .02$, did not reach significance, $F(10,32) = 3.04$, $p < .008$. There were no other meaningful effects, nor did these effects change when stress exposure variables were added. In

contrast, the largest impact on reported distress at the final assessment were maladaptive behaviors, $\beta = 0.54$, $p < .001$, $sr^2 = .16$. Apart from initial distress report, $\beta = 0.32$, $p = .016$, $sr^2 = .05$, there were no other significant effects, $F(10,51) = 6.96$, $p < .001$ and these effects were unchanged when the stress exposure variables were included.

Discussion

This investigation aimed to improve the understanding of moment-level dynamic processes on the stress-to-disease pathway in a high-risk sample of active-duty firefighters. Overall, the results indicated that different forms of stress exposure impacted clinical phenomena in differing ways. Major personal events and daily hassles contributed to health-impairing shifts in sleep and risk-related behaviors that were, in turn, associated with *increases* in symptoms and psychological distress over the 6-month period. These effects were clinically significant, contributing unique variance to disease onset, even when considering a wide range of alternative risk factors. In contrast, aversive incidents that occurred during work as a firefighter predicted healthy behaviors that in turn were predictive of symptom *decreases* over the study period. Because the data were analyzed in two ways (first to identify micro-level processes developing in real time based on weekly experience sampling, and next to identify macro-level processes driving symptom or distress change over months), the results speak to not only what impacted changes in psychological health over six months, but also, what might have caused those changes, thereby providing important new explication of affective disease progression and offering clear targets for intervention.

First, and perhaps most important, is that this research suggests possible clinical targets for risk assessment in at-risk populations. Our finding that SOL was incrementally predictive of symptom *increases* and that maladaptive risk-related behaviors were incrementally predictive of *increases* in psychological distress, above all other measured factors including varied stress exposure, history, treatment, and affect variables, is clinically meaningful and certainly could be applied in assessment practices. Our results also indicated the potential benefits of adaptive healthy behaviors in high-risk populations. Although, there is broad data supporting the health benefits of these behaviors in general, our data provide novel evidence that their enactment in response to work aversive incidents was both common and associated with symptom *decreases*, suggesting some protective psychological benefits. Finally, our data help to facilitate the understanding of the role of stress in symptom exacerbation, demonstrating that different types of stress exposure are associated with different clinical phenomena that ultimately impact symptom increases (or decreases) over time. Indeed, that we tested these associations in a sample of active-duty firefighters with a high probability of a variety of stress exposures may have facilitated the detection of those associations and, it will be important to replicate these findings in other at-risk populations where stress exposure could vary considerably.

In our micro-level analyses, increases in SOL were largely driven by exposure to major personal events (including illnesses, divorce, loss etc.) as compared to minor hassles or critical incident exposure in participants' work as firefighters. Indeed, our results suggest that one additional major personal event reported in a given week was associated with approximately nine additional minutes of delay in time to fall asleep. These sleep delays are clinically significant, as past research comparing differences in objective and subjective SOL between depressed patients versus healthy adults has reported a mean difference of six to ten minutes (Armitage et al., 1997). This finding echoes extant literature on the transdiagnostic relevance of sleep, and further highlight sleep disruption as a pivotal treatment target for at-risk populations (Dolsen et al., 2014).

In contrast, micro-level analysis of maladaptive risk-related behaviors and decreased sleep quantity suggested that both were associated with minor hassles (e.g., interpersonal conflict, parenting stress) but not major personal events nor work aversive incidents. Indeed, both maladaptive behaviors (inclusive of substance use, overspending, risky sex, social avoidance and other risk taking) and overall sleep quantity had significant associations to psychological health, such that greater

maladaptive behaviors and decreased sleep quantity were associated with increases in symptoms and reports of distress at follow-up. These findings build upon past research that has found daily hassles to be predictive of health and psychopathology (Asselmann et al., 2017; DeLongis et al., 1982), as well as suggest a separate line by which minor stress exposure could impact disease onset, one that appears to also be important for consideration.

Interestingly, the only significant association between work aversive incidents and key outcomes was to adaptive healthy behaviors. Moreover, these behaviors significantly predicted symptom variability in the longitudinal analysis, such that greater frequency of adaptive healthy behaviors was associated with a significant *decrease* in symptoms over time. Adaptive healthy behaviors also predicted decreases in SOL, suggesting multiple pathways by which they could exert their protective effects. Moreover, that these behaviors were predicted by work aversive incidents suggests that department culture and perhaps incident management strategies (National Fallen Firefighters Association, 2017) could be encouraging fire-personnel to engage in healthy behaviors following an aversive on-the-job incident. Finally, that positive affect (both trait and state affect indices) was associated with these adaptive healthy behaviors is also consistent with prior research suggesting that they are largely driven by positive rather than negative emotion, across populations (Nylocks et al., 2019).

More broadly, it was evident across our analyses that emotional processes, including trait and sometimes state affect, demonstrated strong associations with risk-related behaviors that held even when considering other relevant variables. Both sets of behaviors, maladaptive and healthy, have been theorized to be enacted in response to emotion: negative emotions for the maladaptive behaviors (Johnson et al., 2013; Selby et al., 2008) and positive emotions for the healthy behaviors (Nylocks et al., 2019), as demonstrated here. Interestingly, we did not find similar associations for the sleep variables, despite a broad literature demonstrating associations between sleep inefficiencies (including shorter sleep quantity and longer SOL) and negative emotion. However, it may be that when symptoms and past psychopathology are also considered, direct associations between sleep and affect are less evident.

There are clear clinical implications for the study's findings. First, the results suggest that assessment of sleep and behaviors in high-risk populations may help to identify vulnerability for common stress-linked disorders, including depression and PTSD. Although further replication is warranted, these findings are certainly consistent with contemporary models of psychopathology, including models that emphasize the role of sleep (Dolsen et al., 2014) and maladaptive risk-related behaviors (Johnson et al., 2013). In addition, these findings suggest that strong emphasis or messaging in support of healthy behaviors within the context of risky professions may pay off with clear psychological benefits. Indeed, our data suggested two pathways by which healthy behaviors were protective, via sleep (at the micro-level), and directly in relation to symptom development (at the macro-level). Finally, these results offer strong support for future research focused on unpacking the variable influence of stress exposure on psychological processes, and provide a methodological template for doing so.

Finally, there were some limitations to consider when interpreting our findings. Although this sample of firefighters was ideal for studying variable stress exposure, they were limited to predominately white, non-Hispanic, males. Thus, additional work is needed to examine potential racial/ethnic or sex differences on these processes in more diverse samples. Indeed, there is evidence suggesting sex-specific vulnerability to stress exposure that warrants consideration (Hodes & Epperson, 2019). As our sample was nearly all male, we were not able to consider sex meaningfully here but are planning replication in more diverse groups. In addition, we focused our analyses on specific clinical phenomena and undoubtedly there were other clinical factors we could have assessed as well as other ways we could have tested these associations. Most important, however, is that these findings be replicated in other samples where sleep and risk behavior rates vary, as our findings could be in part dependent on the behavioral and sleep profiles of firefighters.

In summary, the aim of this investigation was to test the role of stress exposure on clinical variables that contribute to symptom exacerbation in a high-risk group of active-duty firefighters. The results indicated that different forms of stress exposure impacted clinical phenomena in differing ways. In particular, most pernicious to psychological health were major personal events, as well as day-to-day hassles, as compared to highly aversive work incidents. In contrast, aversive incidents that occurred in the line of duty as a firefighter predicted greater healthy behaviors that in turn were uniquely predictive of symptom decreases over a six-month period. Together, these findings shed new light on the stress-to-disease process, offer clear targets for future research, and suggest practical avenues for risk assessment and intervention.

Notes

1. Although dynamic modeling approaches were considered, recent simulation studies suggest that conventional longitudinal models are also appropriate in a sample of this size (e.g., Foster-Johnson & Kromrey, 2018).
2. Nearly all of the remaining 25% of the sample held a rank of Lieutenant or Captain and were still regularly engaged in 911 call responses.
3. Comparison of individuals with and without SCID or SCL-90 follow-up data, using t-tests and chi-square, indicated no differences on key outcome variables (sleep, behaviors, affect, symptoms) or demographics.
4. In the present study yes and urge responses were correlated between .80-.88 across all behaviors.
5. The model effects were unchanged if the two affect variables were excluded but we kept them in for consistency with the micro-level analyses.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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