Accepted for publication in *Clinical Psychological Science* on 10-28-20

A year in the social life of a teenager: Within-person fluctuations in stress, phone communication, and anxiety and depression

Alexandra M. Rodman[1], Constanza M. Vidal Bustamante[1], Meg J. Dennison[2], John C. Flournoy[1], Daniel D. L. Coppersmith[1], Erik C. Nook[1], Steven Worthington[3], Patrick Mair[1] & Katie A. McLaughlin[1]

[1]Department of Psychology, Harvard University

[2]Australian Childhood Foundation

[3]Institute for Quantitative Social Science, Harvard University

Address correspondence to:

Alexandra M. Rodman
Department of Psychology
Harvard University
William James Hall Room 1002
33 Kirkland Street
Cambridge MA 02138

arodman@fas.harvard.edu

Abstract word count:	150
Full document word count:	11,305
Number of tables:	2
Number of figures:	2

ABSTRACT

Stressful life events (SLEs) are strongly associated with the emergence of adolescent anxiety and depression, but the underlying mechanisms remain poorly understood, especially at the within-person level. We investigated how adolescent social communication (i.e., frequency of calls and texts) following SLEs relates to changes in internalizing symptoms in a multi-timescale intensive year-long study (N=30; n=355 monthly observations; n=~5,000 experience-sampling observations). Within-person increases in SLEs were associated with receiving more calls than usual at both monthly- and momentary-levels, and making more calls at the monthly-level. Increased calls were prospectively associated with worsening internalizing symptoms at the monthly-level only, suggesting that SLEs rapidly influences phone communication patterns, but these communication changes may have a more protracted, cumulative influence on internalizing symptoms. Finally, increased incoming calls prospectively mediated the association between SLEs and anxiety at the monthly-level. We identify adolescent social communication fluctuations as a potential mechanism conferring risk for stress-related internalizing psychopathology.

Keywords: Stress, Phone Communication, Depression, Anxiety, Longitudinal

The prevalence of anxiety and depression disorders increases dramatically across adolescence. Adolescence is characterized by elevated risk for first onset of anxiety or depression (Hankin et al., 1998; Kessler et al., 2005; Paus et al., 2008). The onset of internalizing disorders during adolescence is associated with heightened risk for comorbid disorders, greater functional impairment, and a more severe and disabling course (Fombonne et al., 2001a, 2001b; Pine et al., 1998). Understanding the mechanisms that contribute to this heightened risk for anxiety and depression during adolescence may help to identify targets for early interventions.

Exposure to stressful life events (SLEs) is a well-established risk factor for anxiety and depression (Hammen, 1991, 2005; Kendler et al., 1999; Mazure, 1998; McEwen, 2003; McLaughlin et al., 2012), and adolescence is a time of particular vulnerability following exposure to SLEs. The coupling between stress exposure and negative affect and psychopathology is elevated among adolescents relative to children and adults (Espejo et al., 2007; Grant et al., 2003; Grant, Compas, Thurm, McMahon, & Gipson, 2004; Larson & Ham, 1993; Monroe, Rohde, Seeley, & Lewinsohn, 1999). Stressors that are severe (e.g., childhood trauma; McLaughlin et al., 2012) or chronic (Chaby et al., 2015) are particularly likely to lead to the emergence of anxiety and depression; however, even daily hassles and normative stressors (e.g., peer conflict, the break-up of a romantic relationship) are associated with subsequent increases in anxiety and depression symptoms in adolescents (Hammen, 2005; Jenness et al., 2019; M. Monroe et al., 1999). Although much of this research has utilized cross-sectional designs that examine between-person variables, longitudinal studies have also demonstrated associations of SLEs with subsequent changes in anxiety and depression at the within-person level (Cole et al., 2006; Ge et al., 2001; Hankin, 2008). For example, recent work from our group found that within-person deviations in exposure to stress (i.e., increases relative to one's own

average level of stress exposure) predicted subsequent increases in depression symptoms several months later in adolescents (Jenness et al., 2019). However, the mechanisms underlying this tight temporal coupling of stress with anxiety and depression symptoms remain poorly understood. Greater understanding of these mechanisms is essential to identifying and intervening on processes that confer risk for stress-related psychopathology during adolescence. In the current study, we use an intensive longitudinal design to examine the role of social communication as a potential mechanism linking dynamic fluctuations in SLEs with anxiety and depression symptoms during adolescence.

Adolescents experience dramatic changes in the complexity of their social experiences (Nelson et al., 2005). Compared to children, adolescents spend more time with peers than family (Barnes, Hoffman, Welte, Farrell, & Dintcheff, 2007; Larson, 2001), have less stability in peer relationships (Cairns et al., 1995), and place greater importance on peer relationships (Brown, 1990). The need for social belonging is a fundamental human drive (Baumeister & Leary, 1995), and a lack of social support is associated with elevated risk for many negative outcomes, including anxiety and depression (Cacioppo & Hawkley, 2003; Coppersmith et al., 2019; Weeks et al., 1980). This is especially true during adolescence (Somerville, 2013); adolescents exhibit heightened emotional and physiological responses to peer evaluation relative to children or adults (Rodman et al., 2017; Sebastian et al., 2010; Silk et al., 2012; Somerville et al., 2013; Stroud et al., 2009) and social rejection is strongly associated with anxiety and depression symptoms during this period (Prinstein & Aikins, 2004; Williams, 2007).

Given the importance of social relationships and their relation to anxiety and depression during adolescence, it is possible that changes in social behaviors could serve as a mechanism linking SLEs with internalizing psychopathology. Prior work shows that adolescents are more

likely to seek social support from peers and parents during times of heightened perceived stress through both traditional (e.g., face-to-face communication; Galaif, Sussman, Chou, & Wills, 2003) and digital means (e.g., online communication; Frison & Eggermont, 2015; Oh, Lauckner, Boehmer, Fewins-Bliss, & Li, 2013). However, the downstream implications of seeking support through digital means are not clear, and existing evidence on whether this type of social engagement is helpful is mixed.

Decades of research have demonstrated that social support mitigates risk for internalizing problems following exposure to stressors (Cohen, 2004; Cohen & Wills, 1985; Herman-Stahl & Petersen, 1996), suggesting that support-seeking behaviors are an adaptive coping response during periods of stress. Indeed, studies have shown that support-seeking behaviors following SLEs are associated with fewer symptoms of anxiety and depression (Clarke, 2006). Adolescents who endorsed seeking out parental and peer social support following SLEs had enhanced life and relationship satisfaction (Saha et al., 2014), and fewer depression symptoms over time (Murberg & Bru, 2005). Additionally, the quality of parental and peer relationships, including the ability to utilize these relationships for support, is a protective factor associated with lower depression symptoms (Coppersmith et al., 2019; Prinstein et al., 2000), particularly following exposure to stress during adolescence (Alto et al., 2018). Thus, social engagement, even through digital means, following SLEs could be associated with reduced subsequent depression and anxiety symptoms.

Social communication through mobile devices (e.g., phone calls and text messaging) has become one of the most important modes of peer communication among adolescents (Lenhart et al., 2010), and prior work finds mixed results concerning its impact on psychological well-being. While some previous work has suggested that frequency of phone communication, even at high

intensities, is associated with lower levels of loneliness, stronger relational bonds, increased perceived social support, and fewer symptoms of anxiety and depression (George et al., 2018; Padilla-Walker et al., 2012), others have found that high levels of phone communication may be maladaptive, suggesting this dramatic shift in social communication has rapidly changed the landscape of adolescent social life in ways that may not be fully realized (Murdock, 2013). Indeed, studies have found either no relationship between frequency of phone communication and social closeness among adolescents and young adults (Roser et al., 2016; Thomée et al., 2011) or that sending more texts was actually associated with less fulfilling relationships and conversations (Angster et al., 2010). In addition, high volumes of digital communication have been associated with worse wellbeing and daily functioning (Lister-Landman et al., 2017; Sánchez-Martínez & Otero, 2008), including greater symptoms of depression and anxiety (Coyne et al., 2018, 2019; Redmayne et al., 2013; Roser et al., 2016; Thomée et al., 2011). In fact, one study showed that interpersonal stressors were more strongly associated with emotional distress in young adults who engaged in high levels of texting (Murdock, 2013). Of note, the relationships between phone communication and psychological wellbeing have been examined at a various timescales – with some examining how reported frequency of phone communication relates to wellbeing within the same day (George et al., 2018), and others examining these relationships over the course of months or years (Padilla-Walker et al., 2012; Thomée et al., 2011) – and this may contribute to inconsistent findings. In addition, previous work has suggested that while fluctuations in internalizing symptoms occur on the order of weeks to months (Hammen, 2005; S. M. Monroe & Reid, 2008), the tight coupling between stress and negative affect occurs on a more granular scale (i.e., hours to days) (Larson & Ham, 1993; Sliwinski et al., 2009; Stawski et al., 2008; Zawadzki et al., 2019). Thus, extant evidence is

mixed as to the psychological consequences of phone communication intensity, and a greater focus on the impact of *within-person* fluctuations in frequency of social communication following stress examined at multiple timescales could clarify these relationships.

In addition, the vast majority of previous work examining adolescent communication on mobile devices and internalizing problems is based on subjective estimates of phone use, which are subject to inaccuracies and biases inherent in self-reported behaviors (Aydin et al., 2011; Inyang et al., 2009). More recent work has leveraged technological advancements in passively measuring objective phone behaviors via smart-phones (Sequeira et al., 2019; Torous et al., 2016). While some studies examining individual differences in screen time or social media use find no or minimal effects on wellbeing (Orben & Przybylski, 2019a, 2019b), others using within-person approaches have found links between phone behavior (e.g., screen time and frequency of phone communication) and reported stress levels (Sano et al., 2018), personality characteristics (e.g., extraversion; Harari et al., 2019), and anxiety and depression symptoms (Saeb et al., 2015) using this approach. We extend this work by examining how fluctuations in objectively measured phone communication following SLEs relate to anxiety and depression in an intensive longitudinal design.

In the current study, we aimed to determine whether changes in social communication during periods of high exposure to stressors are a potential candidate mechanism through which SLEs might influence internalizing psychopathology during adolescence. We examined anxiety and depression separately, as they represent distinct subcomponents of internalizing symptoms that may relate to social communication in different ways. For example, it may be the case that anxiety is activating and related to hypervigilant monitoring of social communication, whereas depression is related to withdrawal from social communication. We also employed a

combination of both monthly and momentary levels of assessment in order to examine these associations at different timescales. At the monthly level, we examined whether within-person fluctuations in exposure to SLEs were associated with subsequent changes in the frequency of phone communication. In addition, we evaluated whether these fluctuations in the frequency of phone communication were associated with subsequent changes in anxiety and depression symptoms. Finally, we assess whether fluctuations in the frequency of phone communication were a mechanism linking SLEs with anxiety and depression at the within-person level. To examine these associations at a more granular level, we used experience sampling methods (EMA) to assess how associations between perceived stress, phone communication, and reported depressed and anxious affect unfold over the course of a day.

Methods

All code and data are posted to Open Science Framework and can be accessed at https://osf.io/nhfsc/.

Participants

Our sample was designed to examine associations of SLEs, frequency of phone communication, and internalizing symptoms at the within-person level. A sample of 30 female adolescents aged 15-17 participated in a year-long longitudinal study that included 12 in-lab assessments conducted each month (n = 355 monthly assessments) and a total of 12 weeks of ecological momentary assessments (EMA) spread across four waves of three-week periods in which participants reported on stress and affect three times daily (n = nearly 5,000 EMA assessments, see Table 1). Participants were recruited from schools, libraries, public

transportation, and other public spaces in the general community in Seattle, WA between April 2016 and April 2018. Inclusion criteria included female sex, aged 15-17 years, possession of a smart phone with a data plan, and English fluency.

We focused on adolescent females in this age range given higher levels of depression and anxiety symptoms among adolescent females than males (e.g., Hankin et al., 1998; Lewinsohn et al., 1995), as well as more problematic phone use (Roser et al., 2016). Social communication via mobile phones also appears to peak around this age (Coyne et al., 2018). Our study was well-powered to examine within-person associations between SLEs, frequency of phone communication, and symptoms of anxiety and depression over time, with sufficient power (>80%) to detect small within-person effects (as small as $\beta = 0.11$). See *Supplemental Materials* and Figure S4 for more information on the simulated power analysis approach.

Participants were excluded based on the following criteria: IQ < 80, active substance dependence, psychosis, presence of pervasive developmental disorders (e.g., autism), MRI ineligibility (e.g. metal implants), psychotropic medication use, active safety concerns, and inability to commit to the year-long study procedure. A total of 18 participants (60%) had experienced a lifetime mood or anxiety disorder assessed at the first monthly visit, and 12 participants (40%) met criteria for an internalizing disorder during the year they participated in the study, assessed at the final monthly visit. Mood and anxiety disorder were assessed using the Kiddie Schedule for Affective Disorders and Schizophrenia (K-SADS; Kaufman et al., 1997). Twenty-two participants identified as White (73%), 4 as Asian (13%), 2 as Black (7%), and 2 as mixed race (7%). Participants' income-to-needs ratios were computed based on their parents' report of total combined household income and household size. Four participants were in families with income below the poverty line (i.e., income-to-needs ratio below 1; 13%), 12

participants between 1-3 (30%), and 13 participants between 3-10 (33%). One participant did not provide income information. All study procedures were approved by the Institutional Review Board at the University of Washington. Written informed consent was obtained from legal guardians and adolescents provided written assent. Participants were paid increasing amounts of money for each monthly visit, for a total of $905 in possible earnings (Table S1).

Table 1. Descriptive statistics and ICCs for each dependent variable

Dependent variable	*N*	*n*	*M*	*SD*	Range	Possible Range	ICC
Stress							
Monthly Level							
Stressful Life Events	30	356	2.50	3.33	0 - 19	N/A	0.246
Chronic Stress	30	356	4.22	1.87	0 - 8	0 - 8	0.697
Momentary Level							
EMA Stress - Morning	30	1414	3.22	1.85	1 - 7	1 - 7	0.493
EMA Stress - Afternoon	30	1727	3.11	1.81	1 - 7	1 - 7	0.454
EMA Stress - Night	30	1740	3.07	1.84	1 - 7	1 - 7	0.438
Social Behaviors							
Monthly Level							
Outgoing Calls (per day)	28	294	2.15	2.21	0.05 - 16.68	N/A	0.555
Incoming Calls (per day)	28	294	1.54	1.92	0 - 19.6	N/A	0.621
Outgoing Texts (per day)	26	268	33.04	38.18	0.11 - 220.59	N/A	0.774
Incoming Texts (per day)	26	275	39.22	42.07	0.44 - 245.85	N/A	0.724
Momentary Level							
Outgoing Calls - Morning	28	3986	0.78	1.41	0 - 22	N/A	0.055
Outgoing Calls - Afternoon	28	5266	1.41	2.04	0 - 19	N/A	0.108
Outgoing Calls - Night	28	5131	1.58	2.49	0 - 34	N/A	0.125
Incoming Calls - Morning	28	3986	0.60	1.08	0 - 27	N/A	0.068
Incoming Calls - Afternoon	28	5266	0.93	1.38	0 - 22	N/A	0.114
Incoming Calls - Night	28	5131	1.11	2.29	0 - 75	N/A	0.126
Outgoing Texts - Morning	26	6267	8.89	16.27	0 - 210	N/A	0.388
Outgoing Texts - Afternoon	26	6789	11.48	17.67	0 - 173	N/A	0.355
Outgoing Texts - Night	26	6724	17.38	28.22	0 - 308	N/A	0.335
Incoming Texts - Morning	26	6267	10.84	19.90	0 - 704	N/A	0.258
Incoming Texts - Afternoon	26	6789	14.01	21.08	0 - 407	N/A	0.270
Incoming Texts - Night	26	6724	21.10	32.61	0 - 312	N/A	0.292
Clinical Symptoms							
Monthly Level							
Generalized Anxiety (GAD-7)	30	355	5.11	3.83	0 - 14	0 - 21	0.613
Depression (PHQ-9)	30	355	5.41	4.06	0 - 17	0 - 27	0.630
Momentary Level							
EMA Depressed - Morning	30	1418	2.18	1.59	1 - 7	1 - 7	0.444
EMA Depressed - Afternoon	30	1730	2.07	1.53	1 - 7	1 - 7	0.371
EMA Depressed - Night	30	1747	2.06	1.53	1 - 7	1 - 7	0.387
EMA Anxious - Morning	30	1419	3.17	1.77	1 - 7	1 - 7	0.492
EMA Anxious - Afternoon	30	1732	3.07	1.80	1 - 7	1 - 7	0.485
EMA Anxious - Night	30	1750	2.95	1.80	1 - 7	1 - 7	0.462

Note: N = number of subjects, n = number of observations, M = mean, SD = standard deviation, ICC = intra-class correlation

Procedures

Monthly-level assessments of stressful life events and internalizing symptoms were administered at each of the 12 monthly visits. This intensive longitudinal design resulted in a total of 360 possible monthly-level observations of stressful life events and symptoms over the study period, with participants attending 355 out of 360 study visits (98.6% completion rate).

Momentary-level assessments measured perceptions of stress, depressed affect, and anxious affect and were collected via smartphone (through the MetricWire app; www.metricwire.com). Momentary-level assessments of perceived stress and affect were collected three times a day, during the morning, afternoon, and evening, for three weeks at four separate times across the year-long study (i.e., a total of 12 weeks of moment-level assessments across four waves). Participants were counterbalanced to receive the first wave either in the first or second month of the study, and subsequent waves occurred during a random month within each quarter of the rest of the year-long study (i.e., approximately every 3 months). Adopting a multi-wave approach to experience sampling aimed to provide broad coverage of participants' momentary experiences without overburdening them. During experience-sampling periods, participants received three prompts each day in the morning (7:00AM), afternoon (12:00PM), and evening (5:00PM) to complete a short survey about how they felt in that moment. Participants were able to delay surveys for up to 2 hours if they were unable to complete them immediately. Participants responded to nearly 5,000 prompts for each item of perceived stress, depressed affect, and anxious affect (see Table 1).

Unfortunately, a number of issues in the MetricWire (versions 3.1.0 - 3.5.1) tool made it impossible to compute the exact proportion of moment-level assessments that participants completed. Specifically, the software did not consistently record when prompts were sent to

participants, making it impossible to know whether a prompt was ignored by the respondent or not actually sent. Although these issues have been resolved in newer versions of the tool, they had not yet been addressed in the version that was available at the time we started the study. While we cannot compute the exact response rate for momentary-level assessments, we can estimate that if all planned prompts had reached participants, they would have a received a maximum of 7,560 prompts. Thus, at the very least, participants completed more than 65% of all possible prompts, despite these technical issues, which is a rate that is at or above standard for this sampling approach (van Roekel et al., 2019).

Assessments

Exposure to Stress.

Monthly-level assessment. SLEs occurring in the past month were assessed at each study visit using the UCLA Life Stress Interview (Hammen, 1988), a semi-structured interview designed to objectively measure the impact of life events. The interview uses a contextual threat approach for assessing both chronic stress (e.g., ongoing conflict in the home, long-term medical issues) as well as acute life events or episodic stressors (e.g., failing a test, break-up of a romantic relationship). The interview has been extensively validated, adapted for use in adolescents, and considered to be the gold standard for assessing SLEs (Daley et al., 1997; Hammen, 1991). Structured prompts are used to query numerous domains of the child's life (i.e., peers, parents, household/extended family, neighborhood, school, academic, health, finance, and discrimination). Each episodic stressor is probed to determine timing, duration, severity, and coping resources available. Research personnel objectively coded the severity of each experience for a child of that age and sex on a 9-point scale ranging from 1 (none) to 5 (extremely severe), including half-points. These values were transformed to an integer scale from 0-8 for analyses.

Following prior work, a total episodic stress score was computed by taking the sum of the severity scores of all reported events, which reflects both the number and severity of episodic stressors (Hammen et al., 2000), hereafter referred to SLEs. If the participant did not report any SLEs, they received a score of zero for that month. The interview was administered at each monthly visit to assess SLEs occurring since the previous visit. See Table 1 and Figure S1. Though analyses focus on the effect of all types of SLEs on social communication and psychopathology, we provide supplemental analyses examining the effect of interpersonal SLEs and chronic stress on these outcomes reported in *Supplemental Materials* (Tables S2 and S10).

Momentary-level assessment. When prompted by the MetricWire app, participants responded to questions assessing stress in the current moment. In each prompt, stress was defined for participants in the statement: "Stress is a situation where a person feels upset because of something that happened unexpectedly or when they are unable to control important things in their life." Participants then responded to the question "do you feel this kind of stress right now?" on a 7-point scale (1 = *not at all*, 7 = *very stressed*).

Internalizing psychopathology.

Monthly-level assessment. Generalized anxiety symptoms were measured at each study visit with the Generalized Anxiety Disorder-7 (GAD-7) scale, which assesses anxiety symptoms occurring in the last 2 weeks. Seven items are scored on a Likert scale ranging from 0 to 3, with higher scores indicating greater symptom severity. The GAD-7 has good reliability and validity (Spitzer et al., 2006) and demonstrated good internal consistency across all time points in the current study (α=.80-.90; Table 1, Figure S2).

Depression symptoms were measured at each study visit with the Patient Health Questionnaire-9 (PHQ-9) scale, which assesses depression symptoms occurring in the last 2

weeks. Nine items are scored on a Likert scale ranging from 0 to 3, with higher scores indicating greater symptom severity. The PHQ-9 has good reliability and validity (Kroenke et al., 2001) and good internal consistency across all time points in the current study (α=.76-.90; Table 1, Figure S2).

Momentary-level assessment. At each MetricWire prompt, participants also rated their current feelings of depression and anxiety by responding to the questions "how depressed do you feel right now?" and "how anxious do you feel right now?" on 7-point scales (1 = *not at all*, 7 = *very depressed/anxious*). Depression and anxiety were not defined for participants, allowing this measure to capture idiosyncratic conceptualizations of these states.

Phone communication.

Continuous, passive monitoring of phone communication occurred on mobile devices throughout the study period using an app (i.e., *iMazing* for iPhone and *SMS Call & Log Backup* for Android) that downloaded incoming and outgoing phone call and text message logs. Phone call and text activity since the previous visit were downloaded each month. All identifying information was immediately removed from these logs using a custom script. We quantified the number and length of incoming and outgoing communications. At the monthly level of analysis, summaries of calls and texts were aggregated per month and converted into daily averages of phone and text communication to account for differences in the lag time between monthly visits across participants (Table 1, Figure S3). Secondary analyses examining duration of calls and text messages are included in *Supplementary Materials*. At the momentary level of analysis, summaries of calls and texts were aggregated over morning (7:00AM–12:00PM), afternoon (12:00PM–5:00PM), or evening (5:00PM–12:00AM) epochs of the day to parallel the timing of experience sampling surveys.

Statistical Analysis

Overall, analyses focused on evaluating the role that fluctuations in the frequency of social communication might play as a mechanism linking experiences of stress with internalizing symptoms. To do so, we estimated models designed to disaggregate between-person and within-person effects over the course of the year. First, we evaluated these within-person effects at the monthly level while controlling for between-person effects for the following associations: 1) SLEs and internalizing symptoms; 2) SLEs and frequency of social communication (i.e., number of phone calls and text messages); 3) frequency of social communication and internalizing symptoms. Finally, we performed a mediation analysis to evaluate whether fluctuations in the frequency of social communication might serve as a mechanism prospectively linking SLEs with internalizing symptoms. We undertook additional analyses examining these prospective relationships at the momentary-level by examining whether reported stress earlier in the day predicted changes in phone communication later in the day, and whether these fluctuations in phone communication were associated with subsequent depressed or anxious affect.

All regression and mediation analyses were carried out in a Bayesian framework, due to its flexibility in computing models with varied specifications, including a within-person mediation analysis, and intuitive interpretation of the 95% highest posterior density (HPD) credible interval (CR), which signifies a 95% probability of the true population parameter being within the interval. We conducted Bayesian hierarchical linear models with unit of time (i.e., study month or day) nested within subject, with a random intercept allowed to vary across subjects. All models included study month (for monthly-level analyses) or day (for momentary-level analyses) and school status (i.e., months or days dummy coded for in school vs. out of school for summer or weekends) as nuisance covariates. Models were estimated in R 3.5.2 (R

Core Team, 2019) using the *Stan* language (Stan Development Team, 2018) and the *brms* (Bürkner, 2017) and *sjstats* packages (Lüdecke, 2019). Weakly informative priors specifying a Gaussian distribution (M=0, SD=10) were used to represent our diffuse prior knowledge of the fixed and random effects (see *Supplemental Materials* for more information about model specification and Table S3 for complementary analyses). For each parameter, we sampled from 4 stationary Markov chains that approximated the posterior distribution using the Monte Carlo No U-Turn Sampler (Hoffman & Gelman, 2014). Each Markov chain comprised 15,000 sampling iterations, including a burn-in period of 2,500 iterations, which were discarded. Convergence of the 4 chains to a single stationary distribution was assessed via the Gelman-Rubin convergence statistic (Gelman & Rubin, 1992). Highest posterior density 95% CR for all parameters were then calculated from these samples and carried forward for inference, wherein CR that did not contain zero were considered statistically significant.

To dissociate between- and within-person effects of predictors of interest in monthly-level analyses, we used within-individual centering (i.e., centering each participant's observations at the monthly level around their person-specific mean across the year-long study period) and between-subject centering at the year level (i.e., centering each participant's mean level for the entire study period relative to the overall mean for the entire sample). Both within and between person terms were included in all models at the same time. This approach orthogonalizes variation in a given predictor into between- and within-person variability (Enders & Tofighi, 2007), accounting for the dependent nature of the data both over time and within-subject, while controlling for trait-level characteristics of each predictor. When assessing within-person effects at the monthly level, we computed both concurrent and lagged-analysis models to assess for prospective relationships.

In momentary-level analyses, a slightly different approach was taken to constrain analyses to relationships within-day, examining associations from morning to afternoon and afternoon to evening, but not evening to the following morning. In addition, given the structure of the school day, it is possible that these relationships differ across the span of a day. Thus, we first examined the association of morning predictors (i.e., stress, frequency of phone communication) on afternoon outcomes (i.e., frequency of phone communication, depressed and anxious affect), controlling for between-person effects (i.e., the average trait-level of the predictor across the year) and morning level of outcome. The same procedure was repeated for afternoon predictors on evening outcomes. At the momentary level, within-person effects were computed for lagged-analyses only, given the inherently staggered nature of experience sampling surveys and aggregated phone communication values.

Multi-level within person mediation models were estimated when significant associations were found between the predictor and the putative mediator, and between the mediator and outcome. Mediation models were computed with predictor, mediator, and outcomes all measured at the within-person level (i.e., a Level 1-1-1 mediation), by combining coefficients from two separate Bayesian hierarchical models using the same approach described above for the regression models. The first model, from predictor to mediator, yielded an estimate of the coefficient for the *proximal indirect path* (*a*), while the second model, with the dependent variable regressed on the predictor and mediator, yielded coefficients for the *distal indirect path* (*b*) and the *direct path* (*c'*). Coefficients from the *a* and *b* paths were multiplied to calculate the *indirect effect* and this in turn was divided by the *total effect* (*indirect + c'*) to quantify the proportion of variance mediated. Highest posterior density 95% CR were then calculated from these samples for the indirect effect and proportion of variance mediated and used to determine

statistical significance. Only relationships at the monthly-level satisfied the requirements to compute a mediation model, thus mediation model analyses were restricted to monthly-level relationships. All code and data are posted to Open Science Framework and can be accessed at https://osf.io/3amdg.

Results

SLEs and Internalizing Symptoms

When examining relationships at the monthly level, Bayesian hierarchical models revealed significant associations between SLEs and internalizing symptoms (Table 2). Within-person fluctuations in SLEs were significantly associated with increases in anxiety symptoms in the same month, but not the following month. Meanwhile, increases in SLEs were not concurrently associated with depression symptoms in the same month, but predicted worsening depression symptoms the following month (Figure 1, A-B).

At the momentary level, within-person fluctuations in reports of morning stress significantly predicted depressed and anxious affect in the afternoon, while controlling for between-person differences in perceived stress and morning levels of depressed and anxious affect. The same pattern was found when examining the association of afternoon perceived stress with evening depressed and anxious affect (Table 2).

Table 2. Bayesian hierarchical model outcomes at monthly and momentary levels

Monthly Level	Within-person effects (concurrent)			Within-person effects (lagged)		
Model	*B*	*SE*	*95% CR*	*B*	*SE*	*95% CR*
Stressful Life Events predicting						
Generalized Anxiety (GAD-7)	0.133	0.045	**[0.047, 0.221]**	0.027	0.049	[-0.069, 0.121]
Depression (PHQ-9)	0.088	0.048	[-0.001, 0.186]	0.129	0.051	**[0.028, 0.227]**
Stressful Life Events predicting						
Outgoing Calls	0.142	0.031	**[0.080, 0.201]**	0.105	0.031	**[0.040, 0.164]**
Incoming Calls	0.077	0.025	**[0.024, 0.122]**	0.069	0.026	**[0.016, 0.119]**
Outgoing Texts	0.257	0.410	[-0.546, 1.038]	0.031	0.427	[-0.789, 0.874]
Incoming Texts	0.473	0.489	[-0.502, 1.415]	0.261	0.492	[-0.725, 1.205]
Outgoing Calls predicting						
Generalized Anxiety (GAD-7)	0.238	0.096	**[0.048, 0.427]**	0.150	0.098	[-0.044, 0.341]
Depression (PHQ-9)	0.228	0.101	**[0.034, 0.425]**	0.099	0.102	[-0.101, 0.300]
Incoming Calls predicting						
Generalized Anxiety (GAD-7)	0.293	0.118	**[0.055, 0.520]**	0.452	0.126	**[0.198, 0.696]**
Depression (PHQ-9)	0.244	0.122	[-0.002, 0.483]	0.204	0.132	[-0.062, 0.464]
Outgoing Texts predicting						
Generalized Anxiety (GAD-7)	0.013	0.008	[-0.004, 0.029]	0.012	0.010	[-0.007, 0.032]
Depression (PHQ-9)	0.013	0.009	[-0.003, 0.031]	0.002	0.010	[-0.017, 0.021]
Incoming Texts predicting						
Generalized Anxiety (GAD-7)	0.010	0.007	[-0.003, 0.023]	0.008	0.008	[-0.007, 0.024]
Depression (PHQ-9)	0.015	0.007	**[0.001, 0.029]**	0.005	0.008	[-0.011, 0.019]
Momentary Level	Morning → afternoon (lagged)			Afternoon → evening (lagged)		
Model	*B*	*SE*	*95% CR*	*B*	*SE*	*95% CR*
EMA Stress predicting						
EMA Anxiety	0.135	0.032	**[0.073, 0.195]**	0.159	0.029	**[0.100, 0.215]**
EMA Depression	0.048	0.024	**[0.003, 0.100]**	0.063	0.025	**[0.015, 0.111]**
EMA Stress predicting						
Outgoing Calls	-0.002	0.036	[-0.074, 0.066]	0.003	0.031	[-0.055, 0.065]
Incoming Calls	0.047	0.022	**[0.005, 0.087]**	0.007	0.048	[-0.081, 0.100]
Outgoing Texts	-0.181	0.344	[-0.870, 0.467]	-0.274	0.450	[-1.214, 0.573]
Incoming Texts	-0.185	0.393	[-0.980, 0.559]	-0.304	0.506	[-1.258, 0.672]
Outgoing Calls predicting						
EMA Anxiety	0.067	0.044	[-0.017, 0.160]	-0.018	0.024	[-0.065, 0.027]
EMA Depression	0.027	0.035	[-0.046, 0.096]	0.008	0.019	[-0.029, 0.043]
Incoming Calls predicting						
EMA Anxiety	0.026	0.054	[-0.076, 0.135]	-0.043	0.040	[-0.122, 0.034]
EMA Depression	-0.040	0.043	[-0.120, 0.042]	-0.061	0.033	[-0.127, 0.002]
Outgoing Texts predicting						
EMA Anxiety	0.002	0.004	[-0.005, 0.008]	0.000	0.003	[-0.005, 0.006]
EMA Depression	0.001	0.003	[-0.005, 0.006]	0.002	0.002	[-0.003, 0.006]
Incoming Texts predicting						
EMA Anxiety	0.002	0.003	[-0.005, 0.008]	0.002	0.003	[-0.003, 0.007]
EMA Depression	0.002	0.003	[-0.004, 0.007]	0.001	0.002	[-0.003, 0.005]

Note: Statistics reflect outcome of within-person effects. B = unstandardized coefficient; SE = standard error of coefficient; CR = 95% credible interval (15,000 samples); Bold denotes significant effect.

SLEs and Phone Communication

At the monthly level, SLEs were consistently associated with the frequency of phone call behaviors (Table 2). Within-person increases in SLEs were associated with making and receiving

more phone calls than normal during the same month, and these relationships extended into the following month (Figure 1, C-D). SLEs were not associated with frequency of sending or receiving text messages, neither concurrently nor in the following month.

When examining these relationships at the momentary level, reports of greater morning stress than usual predicted an increase in incoming calls in the afternoon, while controlling for between-person levels of perceived stress and incoming calls in the morning. This relationship was not significant when examining afternoon stress to evening incoming calls. Momentary stress did not significantly predict changes in frequency of outgoing calls or texts (Table 2).

Phone Communication and Internalizing Symptoms

At the monthly level, within-person fluctuations in the frequency of phone communication were also related to changes in internalizing symptoms (Table 2). When adolescents made more phone calls than usual, they reported experiencing greater symptoms of anxiety and depression during the same month. When adolescents received more phone calls than normal, they reported more symptoms of anxiety during the same month and the following month. Finally, adolescents that received more text messages than normal reported an increase in depression symptoms during the same month, but not the following month (Figure 1, E-H).

When examining these relationships at the momentary level, frequency of phone communication earlier in the day was not associated with depressed or anxious affect later in the day (Table 2).

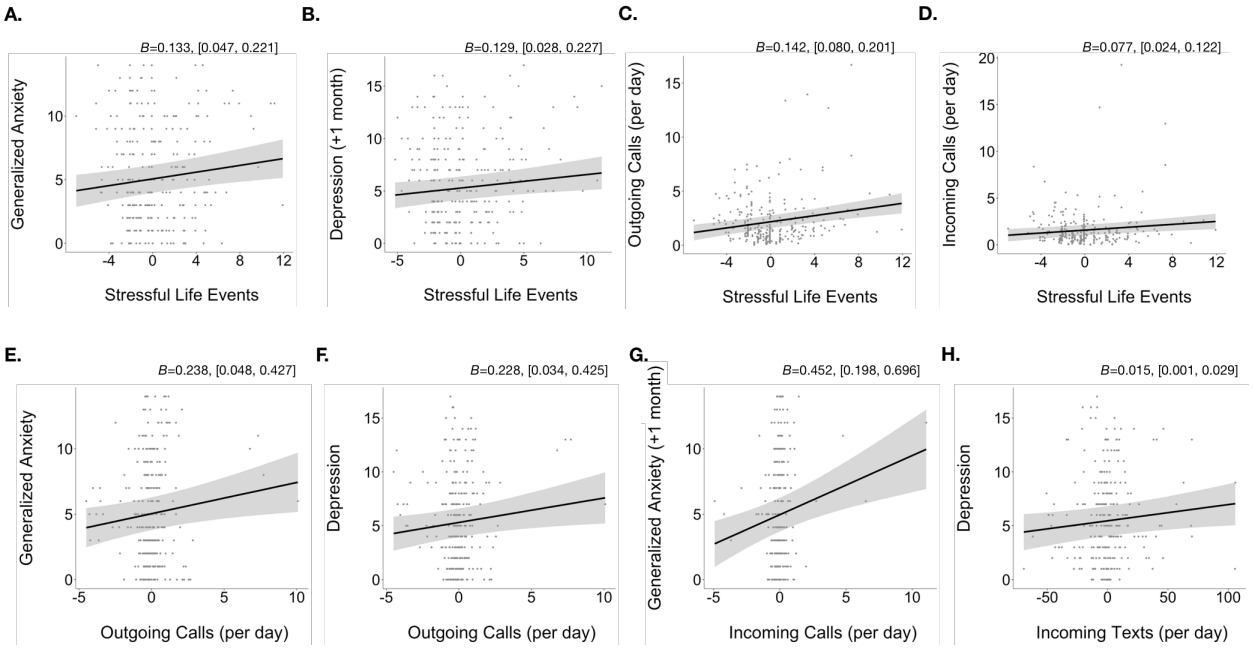


Figure 1. Relationships between SLEs, phone communication and internalizing symptoms at the monthly level. A. Within-person fluctuations in SLEs were positively associated with concurrent symptoms of anxiety (A) and subsequent symptoms of depression the following month (B). Within-person fluctuations in SLEs were positively associated with number of outgoing (C) and incoming phone calls (D) during the same month. A-D: X-axis reflects within-person mean-centered SLEs, and y-axis reflects raw sum score of anxiety (A) and depression (B) or daily average of outgoing (C) and incoming phone calls (D). Within-person fluctuations in number of outgoing calls were positively associated with symptoms of anxiety (E) and depression (F) during the same month, while fluctuations in number of incoming calls were positively associated with symptoms of anxiety during the same month and the following month (G). Fluctuations in number of incoming texts were positively associated with symptoms of depression during the same month (H). E-H: X-axis reflects within-person mean-centered daily averages of phone communication, and y-axis reflects raw sum scores of anxiety and depression symptoms. Black line with shading indicates estimated effect from Bayesian hierarchical model with 95% CR (15,000 samples).

Social Behaviors as a Mediator of Stress and Internalizing Symptoms

When examining the relationships between SLEs, frequency of phone communication, and internalizing symptoms at the within-person level, significant associations across each arm of the indirect path (i.e., SLEs to phone communication; phone communication to internalizing symptoms) emerged at the monthly-level only. Below, we report the median estimate (to account for skew) of the indirect effect and proportion mediated with 95% CR. See Table S4 in the *Supplement* for full statistical results of all mediation models tested.

We determined whether within-person fluctuations in the frequency of phone communication mediated the relationship between stress and internalizing symptoms during the same month (concurrent mediation). We found that fluctuations in number of outgoing calls significantly mediated the within-person relationship between SLEs and depression during the same month, accounting for 42.68% of the total effect of this relationship (Figure 2A). By contrast, neither fluctuations in number of outgoing nor incoming calls mediated the within-person relationship between SLEs and anxiety symptoms in the same month (Table S4).

Next, we examined whether within-person fluctuations in the frequency of phone communication mediated the prospective association between within-person deviations in stress and changes in internalizing symptoms the following month (prospective mediation). Fluctuations in number of incoming calls significantly mediated the relationship between changes in SLEs and subsequent anxiety symptoms the following month, accounting for 39.38% of the total effect of this relationship (Figure 2B). When also lagging the relationship between stress and incoming calls, we found that the number of incoming calls significantly mediated 38.70% of the total effect of the relationship between previous month's SLEs and the following month's changes in anxiety symptoms (Figure 2C). This prospective association suggests that there may be a sequential relationship to these factors, wherein stress may stir up an influx of phone communication that may drive worsening anxiety symptoms. While the current study cannot speak to the exact nature of this influx in phone calls, secondary analyses aimed at understanding its correlates suggest that within-person fluctuations in co-rumination may play a role in these outcomes (*Supplemental Materials,* Table S5).

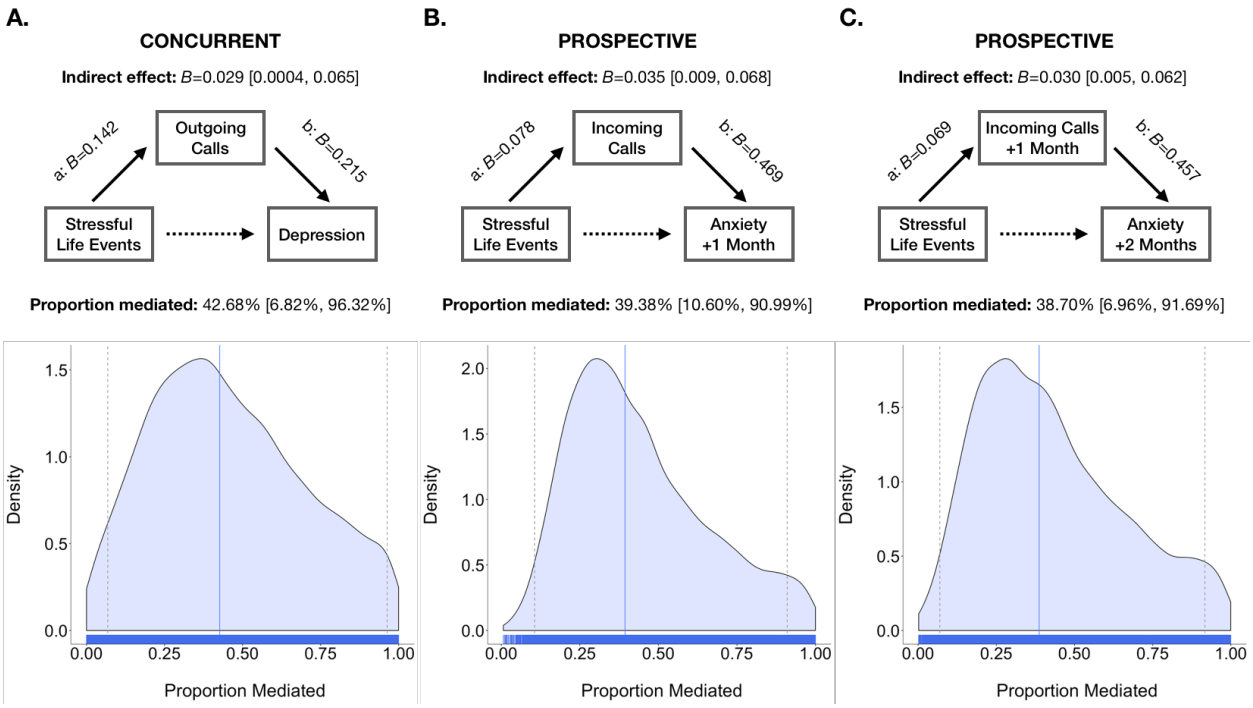


Figure 2. Within person fluctuations in number of phone call mediates the relationship between changes in stress and depression and anxiety symptoms. Changes in number of outgoing phone calls mediated the relationship between SLEs and concurrent symptoms of depression (A). Within-person fluctuations in number of incoming phone calls mediated the relationships between stressful live events and subsequent symptoms of anxiety (B) and previous SLEs and subsequent symptoms of anxiety (C). Figures show Bayesian mediation model results and 95% HPD CR displayed in brackets (15,000 samples). Density and rug plots display the posterior density of the estimated proportion mediated (blue line indicates median estimate; gray dashed lines indicate 95% CR).

Discussion

Understanding the mechanisms that explain how SLEs foment internalizing symptoms during adolescence is crucial for early intervention and prevention efforts. Given the dramatic shifts in social experiences that occur during adolescence, we examined social communication as a potential mechanism linking stressors to internalizing psychopathology in adolescent females by objectively characterizing the frequency of phone calls and text messaging. Examination of these relationships at multiple timescales in an intensive longitudinal design positioned us to isolate within-person fluctuations to determine how these associations unfolded dynamically

over time. This approach revealed robust associations between within-person fluctuations in SLEs and frequency of phone communication. Specifically, when adolescents experienced more stressors than was typical for them, they made and received more phone calls during the same month and the following month. The relationship between perceived stress and subsequent changes in incoming calls was also observed at the momentary-level. These changes in social communication were related to fluctuations in internalizing symptoms, but not momentary affect, such that months characterized by greater frequency of phone and text communication than usual were associated with within-person increases in both current and future anxiety or depression symptoms. Finally, mediation analyses showed that increases in incoming phone calls accounted for a significant proportion of the prospective within-person relationship between stress and subsequent anxiety symptoms the following month.

Given that evidence linking psychological wellbeing and phone communication is mixed (George et al., 2018; Murdock, 2013; Padilla-Walker et al., 2012; Roser et al., 2016), we sought to clarify this relationship using an intensive longitudinal design that capitalizes on the ability to passively collect actual frequency of phone communication. This approach afforded the ability to examine the sequential unfolding of the relationships between stressors, phone communication, and internalizing symptoms at multiple timescales over a year, while using multi-modal approaches of gathering data to reduce shared variance in measurement (i.e., standardized interview, passive digital monitoring, and subjective report). With these advancements, we provide evidence suggesting that within-person fluctuations in SLEs are associated with changes in the frequency of phone communication that, in turn, are associated with anxiety and depression symptoms concurrently and prospectively. In contrast, the duration of calls and length of text messages were not significantly related to stressors or psychopathology, with the

exception of outgoing call length, whereby a weak, positive relationship was related to concurrent symptoms of depression. Thus, frequency of communication remains the metric of social communication that is associated with psychopathology following stress. Greater research is needed to identify the mechanisms through which stressors relate specifically to the frequency of social communication; these could include increases in rumination and worry (e.g., Michl et al., 2013), reassurance seeking (Joiner et al., 1999), and desire for social support that occur following stressful life events. Contrary to the notion that enhanced social engagement would universally buffer adolescents from the harmful effects of stress, these findings highlight the potential negative consequences of certain forms of social communication during adolescence, particularly during periods characterized by greater levels of stress.

The consequences of social engagement may depend on both the nature of support-seeking behavior and whether it is met with a supportive response (Frison & Eggermont, 2015). A variety of social responses to stress can be maladaptive, including reassurance-seeking and co-rumination. Reassurance-seeking involves repeatedly soliciting confirmation of positive standing from others, that over time can lead to a deterioration of relationships and worsening of internalizing symptoms (Joiner et al., 1999; Potthoff et al., 1995; Prinstein et al., 2005). Co-rumination is characterized as dwelling on problems in conversation with others; although this tendency strengthens social bonds, it also predicts worsening symptoms of anxiety and depression in adolescents (Rose, 2002; Schwartz-Mette & Rose, 2012). In addition, while not measurable in this study, the extent to which support-seeking behaviors are actually met with an empathic response can mitigate or increase risk for stress-related internalizing symptoms (Frison & Eggermont, 2015). Thus, certain kinds of social engagement following stressors could exacerbate risk for subsequent psychopathology.

When characterizing monthly within-person fluctuations in SLEs, social communication, and symptoms of anxiety and depression over the course of a year, we replicate prior findings by demonstrating that within-person fluctuations in exposure to stress—measured using a gold-standard interview-based approach—were concurrently and prospectively associated with changes in internalizing symptoms (Jenness et al., 2019). We extend this literature by showing this relationship on both the monthly and momentary level of assessment, and reaffirm that these deleterious effects of stress on mental health motivate additional research on the mechanisms underlying this connection.

We also found that when adolescents experienced more SLEs than was normal for them, they engaged in more phone calls during the same month and the following month, a pattern that also emerged at the momentary-level for incoming calls, suggesting a rapid coupling between stress and phone communication. A similar pattern was found for interpersonal stressors and phone communication, wherein greater interpersonal stress was associated with higher frequency of phone call, but not text message communication. Chronic stress was also similarly positively related to number of phone calls; however, chronic stress was also associated with reduced frequency of incoming text messages during the same month (Table S2). This dissociation may be explained by the different relational purposes of phone calls and text messages serve. While adolescents typically reserve conversations with parents and discussions about major life events for phone conversations (Madell & Muncer, 2007), text messaging among adolescents is used to maintain and reinforce existing bonds with close friends (Blair et al., 2015; Bryant et al., 2006). It is possible that during times of more severe or ongoing stress, adolescents pull for more substantive social support by way of phone calls, while reducing engagement in text messages that serve a relational maintenance function and reflect more superficial communication.

In order to evaluate whether these responses to stress were adaptive or maladaptive, we examined how fluctuations in the frequency of social communication related to symptoms of anxiety or depression. While not associated with momentary affect at a more granular time scale, analyses at the monthly level show that making more phone calls than was usual was associated with increased symptoms of anxiety and depression during the same month, and greater incoming calls than usual was both concurrently and prospectively associated with worsening anxiety the following month. Moreover, receiving more phone calls following exposure to stressors accounted for a significant proportion of the prospective relationship between within-person increases in SLEs and subsequent anxiety symptoms. The longitudinal nature of these data allow us to draw inferences about the directionality of these relationships (Maxwell & Cole, 2007), which suggest that an influx of phone calls following SLEs may drive subsequent worsening symptoms of anxiety. The dissociation in findings based on time-scale may clarify the temporal dynamics of how phone communication impacts well-being over time. Specifically, while within-day changes in phone communication were not significantly associated with depressed or anxious *affect,* the associations of increased phone communication on depression and anxiety *symptoms* may arise more gradually with an accumulation of increased communication, given than a time frame of weeks to months is more relevant to symptom development and disorder onset (Hammen, 2005; Kendler et al., 1999). This general pattern extends previous work showing that young adults that are high-volume texters demonstrated stronger coupling between stress and internalizing symptoms (Murdock, 2013), by using a within-subjects mediation design in adolescents rather than a cross-sectional moderation design. Together, these findings suggest that within-person fluctuations in the frequency of social communication may be a potential mechanism linking stressors with internalizing symptoms.

These findings may point to high intensity phone communication relative to one's baseline as indicative of a marker of risk for psychopathology following exposure to stress.

Although increases in both making and receiving calls was associated with SLEs and concurrent anxiety and depression symptoms, only increases in the number of incoming calls was prospectively linked to worsening of anxiety the following month. This pattern was not observed for outgoing calls, which raises some interesting possible explanations. The influx in incoming calls could reflect a response from maladaptive social behaviors following stress. While unlikely to be explained by reassurance-seeking behavior, which can erode relationships and result in less social engagement from others (Potthoff et al., 1995), co-rumination is one potential explanation for this pattern. To test this possibility, we examined whether within-person fluctuations in self-reported co-rumination was associated with SLEs, phone communication, or internalizing psychopathology (see *Supplemental Materials* and Table S5). We found that within-person increases in reported co-rumination were associated with greater frequency of incoming phone calls that same month and, consistent with prior work (Rose, 2002), worsening internalizing symptoms in the same month and the following month. While not associated with SLEs, co-rumination may be a contributing factor that could help explain why increases in incoming phone calls following stress led to worsening symptoms of anxiety. Tracking of social communication, captured here by frequency of phone calls and text messages, could represent a stress-related marker of clinical risk that reflects complex social and psychological factors, that may include co-ruminative behaviors. Another possible explanation for the particularly strong link between incoming calls and subsequent anxiety is that the calls themselves involve stressful interpersonal interactions, such as conflict with peers, bullying, or increased monitoring from parents. While the current study was not designed to examine these questions, future work

should attempt to determine whether phone communication is with parents or peers and, taking a step further, introduce content analysis (e.g., from text messages) to extract the nature of the communication. While informative, we have restricted our analyses to frequency of communication, as content analysis pushes the boundaries of ethics and protection of privacy (Jacobson et al., 2020).

Taken together, these findings suggest that social behaviors, such as frequency of phone communication, is a marker of risk for psychopathology following stress, and may serve as a mechanism linking the two. However, the current research should be considered in light of its limitations. The interpretation of changes in the frequency of social communication is limited in that it is unknown whether communication is with a peer or parent, and this relationship type influences communication method and support seeking behavior (Blair et al., 2015; Bryant et al., 2006; Madell & Muncer, 2007). Moreover, perceived social support from parents as compared to peers during adolescence could differentially impact risk for depression (Stice et al., 2004). Future work should identify whether the social communication driving the link between stress and psychopathology is primarily explained by communication with peers or parents. Additionally, the scope of social communication here is limited to frequency of phone calls and text messages, though communication may also be taking place in person or via other social media platforms popular among adolescents, such as WhatsApp, SnapChat, and Instagram. Future work should aim to isolate the unique contribution of phone communication to the current finings, as compared to changes in general phone usage (e.g., screen time) or general sociability (e.g., face-to-face communication). Furthermore, as discussed, the current analyses are limited to a sample of thirty adolescent females, which limits the generalizability of the current study. While the sample size is restricted due to the intensive longitudinal nature of the study design,

the sample includes community members that are representative for a wide range of socioeconomic status and risk for psychopathology (see *Methods*). The focus on females was chosen by design to reduce interindividual variability and capitalize on a group that is at particularly high risk for problematic phone use and internalizing problems (Hankin et al., 1998; Lewinsohn et al., 1995; Roser et al., 2016). However, future work should aim to generalize these findings to a larger sample including males and investigate any gender-specific effects. Finally, analytical approaches used in the current work should be leveraged to identify intervention points based on how frequency of social communication can confer risk or resilience to psychopathology following stress (Nahum-Shani et al., 2018).

The current research suggests that increases in social communication using mobile devices relative to adolescents' average usage could portend negative consequences for adolescents. These findings do not necessarily suggest that adolescents should not communicate with others following stressful events, but rather it may be important to consider the nature of that communication. In addition to the intense and constant attunement to potential communication and the accompanying anxiety associated with phone separation (Skierkowski & Wood, 2012), some electronic communication may lead to more opportunities for stress (Weinstein & Selman, 2016), including greater potential for misunderstanding (Coyne et al., 2011) or embolden more negative treatment or bullying (Jones et al., 2013). Furthermore, some cell phone users exhibit compulsive behaviors termed 'problematic cell phone use' (Billieux, 2012), which can lead to dysfunction (e.g., not completing expected demands), stress and symptoms of anxiety and depression in both adolescents and adults (Coyne et al., 2018, 2019; Lister-Landman et al., 2017; Murdock, 2013; Redmayne et al., 2013; Roser et al., 2016; Thomée et al., 2011). Thus, it is important to closely examine social behaviors in the form of phone

communication as a mechanism through which SLEs might contribute to internalizing problems in adolescents. Whether these findings extend to other domains of functioning, like relationship quality, risk behaviors, and substance use, is an important goal for future research.

Conclusion

Although SLEs are a known risk factor for symptoms of depression and anxiety, the mechanisms underlying this tight temporal coupling remain poorly understood. Here, we used an intensive longitudinal design and leveraged digital phenotyping methods to understand how dynamic changes in social behaviors following exposure to SLEs relate to the emergence of internalizing symptoms at multiple timescales. We find that within-person fluctuations in the frequency of social communication statistically explain the prospective link between stressful life events and anxiety symptoms. This work provides evidence for one pathway by which stressors can lead to worsening of internalizing symptoms and identifies frequency of social communication as a social process that confers risk for psychopathology following exposure to SLEs. Identifying mechanisms of risk using smartphone technology will allow for future innovation in how, when, and with whom to intervene and mitigate risk for stress-related psychopathology.

Acknowledgements

This work was supported by the National Institute of Mental Health (R56-119194) to KAM, a One Mind Institute Rising Star Award to KAM, a Jacobs Foundation Early Career Research Fellowship to KAM.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

K.A.M., M.J.D., and A.M.R. designed the research; A.M.R. analyzed the data and drafted the manuscript; P.M. and S.W. provided statistical consultation; K.A.M., C.M.V.B., M.J.D., J.C.F., D.D.L.D., E.C.N., S.W., and P.M. provided critical comments and revisions. All authors approved the final version of the manuscript for submission.

References

Alto, M., Handley, E., Rogosch, F., Cicchetti, D., & Toth, S. (2018). Maternal relationship quality and peer social acceptance as mediators between child maltreatment and adolescent depressive symptoms: Gender differences. *Journal of Adolescence*, *63*, 19–28. https://doi.org/10.1016/j.adolescence.2017.12.004

Angster, A., Frank, M., & Lester, D. (2010). An Exploratory Study of Students' Use of Cell Phones, Texting, and Social Networking Sites. *Psychological Reports*, *107*(2), 402–404. https://doi.org/10.2466/17.PR0.107.5.402-404

Aydin, D., Feychting, M., Schüz, J., Andersen, T. V., Poulsen, A. H., Prochazka, M., Klæboe, L., Kuehni, C. E., Tynes, T., & Röösli, M. (2011). Predictors and overestimation of recalled mobile phone use among children and adolescents. *Progress in Biophysics and Molecular Biology*, *107*(3), 356–361. https://doi.org/10.1016/j.pbiomolbio.2011.08.013

Barnes, G. M., Hoffman, J. H., Welte, J. W., Farrell, M. P., & Dintcheff, B. A. (2007). Adolescents' time use: Effects on substance use, delinquency and sexual activity. *Journal of Youth and Adolescence*, *36*(5), 697–710. https://doi.org/10.1007/s10964-006-9075-0

Baumeister, R. F., & Leary, M. R. (1995). The need to belong: Desire for interpersonal attachments as a fundamental human motivation. *Psychological Bulletin*, *117*(3), 497–529. https://doi.org/10.1037/0033-2909.117.3.497

Billieux, J. (2012). Problematic Use of the Mobile Phone: A Literature Review and a Pathways Model. *Current Psychiatry Reviews*, *8*(4), 299–307. https://doi.org/info:doi/10.2174/157340012803520522

Blair, B. L., Fletcher, A. C., & Gaskin, E. R. (2015). Cell Phone Decision Making: Adolescents' Perceptions of How and Why They Make the Choice to Text or Call. *Youth & Society*, *47*(3), 395–411. https://doi.org/10.1177/0044118X13499594

Brown, B. B. (1990). Peer groups and peer cultures. In S. S. Feldman & G. R. Elliott (Eds.), *At the threshold: The developing adolescent* (pp. 171–196). Harvard University Press.

Bryant, J. A., Sanders-Jackson, A., & Smallwood, A. M. K. (2006). IMing, Text Messaging, and Adolescent Social Networks. *Journal of Computer-Mediated Communication*, *11*(2), 577–592. https://doi.org/10.1111/j.1083-6101.2006.00028.x

Bürkner, P.-C. (2017). brms: An R Package for Bayesian Multilevel Models Using Stan. *Journal of Statistical Software*, *80*(1). https://doi.org/10.18637/jss.v080.i01

Cacioppo, J. T., & Hawkley, L. C. (2003). Social Isolation and Health, with an Emphasis on Underlying Mechanisms. *Perspectives in Biology and Medicine*, *46*(3), S39–S52. https://doi.org/10.1353/pbm.2003.0063

Cairns, R. B., Leung, M.-C., Buchanan, L., & Cairns, B. D. (1995). Friendships and Social Networks in Childhood and Adolescence: Fluidity, Reliability, and Interrelations. *Child Development*, *66*(5), 1330–1345. https://doi.org/10.1111/j.1467-8624.1995.tb00938.x

Chaby, L. E., Cavigelli, S. A., Hirrlinger, A. M., Caruso, M. J., & Braithwaite, V. A. (2015). Chronic unpredictable stress during adolescence causes long-term anxiety. *Behavioural Brain Research*, *278*, 492–495. https://doi.org/10.1016/j.bbr.2014.09.003

Clarke, A. T. (2006). Coping with Interpersonal Stress and Psychosocial Health Among Children and Adolescents: A Meta-Analysis. *Journal of Youth and Adolescence*, *35*(1), 10–23. https://doi.org/10.1007/s10964-005-9001-x

Cohen, S. (2004). Social Relationships and Health. *American Psychologist*, 9.

Cohen, S., & Wills, T. A. (1985). Stress, social support, and the buffering hypothesis. *Psychological Bulletin*, *98*(2), 310–357. https://doi.org/10.1037/0033-2909.98.2.310

Cole, D. A., Nolen-Hoeksema, S., Girgus, J., & Paul, G. (2006). Stress exposure and stress generation in child and adolescent depression: A latent trait-state-error approach to longitudinal analyses. *Journal of Abnormal Psychology*, *115*(1), 40–51. https://doi.org/10.1037/0021-843X.115.1.40

Coppersmith, D. D. L., Kleiman, E. M., Glenn, C. R., Millner, A. J., & Nock, M. K. (2019). The dynamics of social support among suicide attempters: A smartphone-based daily diary study. *Behaviour Research and Therapy*, *120*, 103348. https://doi.org/10.1016/j.brat.2018.11.016

Coyne, S. M., Padilla-Walker, L. M., & Holmgren, H. G. (2018). A Six-Year Longitudinal Study of Texting Trajectories During Adolescence. *Child Development*, *89*(1), 58–65. https://doi.org/10.1111/cdev.12823

Coyne, S. M., Stockdale, L., & Summers, K. (2019). Problematic cell phone use, depression, anxiety, and self-regulation: Evidence from a three year longitudinal study from adolescence to emerging adulthood. *Computers in Human Behavior*, *96*, 78–84. https://doi.org/10.1016/j.chb.2019.02.014

Daley, S. E., Hammen, C., Burge, D., Davila, J., Paley, B., Lindberg, N., & Herzberg, D. S. (1997). Predictors of the generation of episodic stress: A longitudinal study of late adolescent women. *Journal of Abnormal Psychology*. https://doi.org/10.1037/0021-843X.106.2.251

Enders, C. K., & Tofighi, D. (2007). Centering predictor variables in cross-sectional multilevel models: A new look at an old issue. *Psychological Methods*, *12*(2), 121–138. https://doi.org/10.1037/1082-989X.12.2.121

Espejo, E. P., Hammen, C. L., Connolly, N. P., Brennan, P. A., Najman, J. M., & Bor, W. (2007). Stress Sensitization and Adolescent Depressive Severity as a Function of Childhood Adversity: A Link to Anxiety Disorders. *Journal of Abnormal Child Psychology*, *35*(2), 287–299. https://doi.org/10.1007/s10802-006-9090-3

Fombonne, E., Wostear, G., Cooper, V., Harrington, R., & Rutter, M. (2001a). The Maudsley long-term follow-up of child and adolescent depression: 1. Psychiatric outcomes in adulthood. *The British Journal of Psychiatry*, *179*(3), 210–217. https://doi.org/10.1192/bjp.179.3.210

Fombonne, E., Wostear, G., Cooper, V., Harrington, R., & Rutter, M. (2001b). The Maudsley long-term follow-up of child and adolescent depression: 2. Suicidality, criminality and social dysfunction in adulthood. *The British Journal of Psychiatry*, *179*(3), 218–223. https://doi.org/10.1192/bjp.179.3.218

Frison, E., & Eggermont, S. (2015). The impact of daily stress on adolescents' depressed mood: The role of social support seeking through Facebook. *Computers in Human Behavior*, *44*, 315–325. https://doi.org/10.1016/j.chb.2014.11.070

Galaif, E. R., Sussman, S., Chou, C.-P., & Wills, T. A. (2003). Longitudinal Relations Among Depression, Stress, and Coping in High Risk Youth. *Journal of Youth and Adolescence*, *32*(4), 243–258. https://doi.org/10.1023/A:1023028809718

Ge, X., Conger, R. D., & Elder Jr., G. H. (2001). Pubertal transition, stressful life events, and the emergence of gender differences in adolescent depressive symptoms. *Developmental Psychology*, *37*(3), 404–417. https://doi.org/10.1037/0012-1649.37.3.404

Gelman, A., & Rubin, D. B. (1992). Inference from Iterative Simulation Using Multiple Sequences. *Statistical Science*, *7*(4), 457–472. https://doi.org/10.1214/ss/1177011136

George, M. J., Russell, M. A., Piontak, J. R., & Odgers, C. L. (2018). Concurrent and Subsequent Associations Between Daily Digital Technology Use and High-Risk Adolescents' Mental Health Symptoms. *Child Development*, *89*(1), 78–88. https://doi.org/10.1111/cdev.12819

Grant, K. E., Compas, B. E., Stuhlmacher, A. F., Thurm, A. E., McMahon, S. D., & Halpert, J. A. (2003). Stressors and child and adolescent psychopathology: Moving from markers to mechanisms of risk. *Psychological Bulletin*, *129*(3), 447–466. https://doi.org/10.1037/0033-2909.129.3.447

Grant, K. E., Compas, B. E., Thurm, A. E., McMahon, S. D., & Gipson, P. Y. (2004). Stressors and Child and Adolescent Psychopathology: Measurement Issues and Prospective Effects. *Journal of Clinical Child & Adolescent Psychology*, *33*(2), 412–425. https://doi.org/10.1207/s15374424jccp3302_23

Hammen, C. (1988). Self-cognitions, stressful events, and the prediction of depression in children of depressed mothers. *Journal of Abnormal Child Psychology*. https://doi.org/10.1007/BF00913805

Hammen, C. (1991). Generation of stress in the course of unipolar depression. *Journal of Abnormal Psychology*, *100*(4), 555–561. https://doi.org/10.1037/0021-843X.100.4.555

Hammen, C. (2005). Stress and Depression. *Annual Review of Clinical Psychology*, *1*(1), 293–319. https://doi.org/10.1146/annurev.clinpsy.1.102803.143938

Hammen, C., Henry, R., & Daley, S. E. (2000). Depression and sensitization to stressors among young women as a function of childhood adversity. *Journal of Consulting and Clinical Psychology*, *68*(5), 782–787. https://doi.org/10.1037//0022-006X.68.5.782

Hankin, B. L. (2008). Rumination and Depression in Adolescence: Investigating Symptom Specificity in a Multiwave Prospective Study. *Journal of Clinical Child & Adolescent Psychology*, *37*(4), 701–713. https://doi.org/10.1080/15374410802359627

Hankin, B. L., Abramson, L. Y., Moffitt, T. E., Silva, P. A., McGee, R., & Angell, K. E. (1998). Development of depression from preadolescence to young adulthood: Emerging gender differences in a 10-year longitudinal study. *Journal of Abnormal Psychology*, *107*(1), 128–140. https://doi.org/10.1037/0021-843X.107.1.128

Harari, G. M., Müller, S. R., Stachl, C., Wang, R., Wang, W., Bühner, M., Rentfrow, P. J., Campbell, A. T., & Gosling, S. D. (2019). Sensing sociability: Individual differences in young adults' conversation, calling, texting, and app use behaviors in daily life. *Journal of Personality and Social Psychology*. https://doi.org/10.1037/pspp0000245

Herman-Stahl, M., & Petersen, A. C. (1996). The protective role of coping and social resources for depressive symptoms among young adolescents. *Journal of Youth and Adolescence*, *25*(6), 733–753. https://doi.org/10.1007/BF01537451

Hoffman, M. D., & Gelman, A. (2014). The No-U-Turn Sampler: Adaptively Setting Path Lengths in Hamiltonian Monte Carlo. *Journal of Machine Learning Research*, 31.

Inyang, I., Benke, G., Morrissey, J., McKenzie, R., & Abramson, M. (2009). How well do adolescents recall use of mobile telephones? Results of a validation study. *BMC Medical Research Methodology*, *9*(1), 36. https://doi.org/10.1186/1471-2288-9-36

Jacobson, N. C., Bentley, K. H., Walton, A., Wang, S. B., Fortgang, R. G., Millner, A. J., Coombs, G., Rodman, A. M., & Coppersmith, D. D. L. (2020). Ethical Dilemmas Posed by Mobile Health and Machine Learning within Research in Psychiatry. *Bulletin of the World Health Organization*.

Jenness, J. L., Peverill, M., King, K. M., Hankin, B. L., & McLaughlin, K. A. (2019). Dynamic associations between stressful life events and adolescent internalizing psychopathology in a multiwave longitudinal study. *Journal of Abnormal Psychology*, *128*(6), 596–609. https://doi.org/10.1037/abn0000450

Joiner, T. E., Katz, J., & Lew, A. (1999). Harbingers of Depressotypic Reassurance Seeking: Negative Life Events, Increased Anxiety, and Decreased Self-Esteem. *Personality and Social Psychology Bulletin*, *25*(5), 632–639. https://doi.org/10.1177/0146167299025005008

Jones, L. M., Mitchell, K. J., & Finkelhor, D. (2013). Online harassment in context: Trends from three Youth Internet Safety Surveys (2000, 2005, 2010). *Psychology of Violence*, *3*(1), 53–69. https://doi.org/10.1037/a0030309

Kaufman, J., Birmaher, B., Brent, D., Rao, U., Flynn, C., Moreci, P., Williamson, D., & Ryan, N. (1997). Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and Lifetime Version (K-SADS-PL): Initial Reliability and Validity Data. *Journal of the American Academy of Child & Adolescent Psychiatry*, *36*(7), 980–988. https://doi.org/10.1097/00004583-199707000-00021

Kendler, K. S., Karkowski, L. M., & Prescott, C. A. (1999). Causal Relationship Between Stressful Life Events and the Onset of Major Depression. *American Journal of Psychiatry*, *156*(6), 837–841. https://doi.org/10.1176/ajp.156.6.837

Kessler, R. C., Berglund, P., Demler, O., Jin, R., Merikangas, K. R., & Walters, E. E. (2005). Lifetime Prevalence and Age-of-Onset Distributions of DSM-IV Disorders in the National Comorbidity Survey Replication. *Archives of General Psychiatry*, *62*(6), 593–602. https://doi.org/10.1001/archpsyc.62.6.593

Kroenke, K., Spitzer, R. L., & Williams, J. B. W. (2001). The PHQ-9. *Journal of General Internal Medicine*, *16*(9), 606–613. https://doi.org/10.1046/j.1525-1497.2001.016009606.x

Larson, R. (2001). How U.S. Children and Adolescents Spend Time: What It Does (and Doesn't) Tell Us About Their Development. *Current Directions in Psychological Science*, *10*(5), 160–164. https://doi.org/10.1111/1467-8721.00139

Larson, R., & Ham, M. (1993). Stress and "storm and stress" in early adolescence: The relationship of negative events with dysphoric affect. *Developmental Psychology*, *29*(1), 130–140. https://doi.org/10.1037/0012-1649.29.1.130

Lenhart, A., Ling, R., Campbell, S., & Purcell, K. (2010). *Teens and Mobile Phones: Text Messaging Explodes as Teens Embrace It as the Centerpiece of Their Communication Strategies with Friends*. Pew Internet & American Life Project. https://eric.ed.gov/?id=ED525059

Lewinsohn, P. M., Gotlib, I. H., & Seeley, J. R. (1995). Adolescent Psychopathology: IV. Specificity of Psychosocial Risk Factors for Depression and Substance Abuse in Older Adolescents. *Journal of the American Academy of Child & Adolescent Psychiatry*, *34*(9), 1221–1229. https://doi.org/10.1097/00004583-199509000-00021

Lister-Landman, K. M., Domoff, S. E., & Dubow, E. F. (2017). The role of compulsive texting in adolescents' academic functioning. *Psychology of Popular Media Culture*, *6*(4), 311–325. https://doi.org/10.1037/ppm0000100

Lüdecke, D. (2019). *sjstats: Statistical Functions for Regression Models* (0.17.6) [Computer software]. https://CRAN.R-project.org/package=sjstats

Madell, D. E., & Muncer, S. J. (2007). Control over Social Interactions: An Important Reason for Young People's Use of the Internet and Mobile Phones for Communication? *CyberPsychology & Behavior*, *10*(1), 137–140. https://doi.org/10.1089/cpb.2006.9980

Maxwell, S. E., & Cole, D. A. (2007). Bias in cross-sectional analyses of longitudinal mediation. *Psychological Methods*, *12*(1), 23–44. https://doi.org/10.1037/1082-989X.12.1.23

Mazure, C. M. (1998). Life Stressors as Risk Factors in Depression. *Clinical Psychology: Science and Practice*, *5*(3), 291–313. https://doi.org/10.1111/j.1468-2850.1998.tb00151.x

McEwen, B. S. (2003). Mood disorders and allostatic load. *Biological Psychiatry*, *54*(3), 200–207. https://doi.org/10.1016/S0006-3223(03)00177-X

McLaughlin, K. A., Green, J. G., Gruber, M. J., Sampson, N. A., Zaslavsky, A. M., & Kessler, R. C. (2012). Childhood Adversities and First Onset of Psychiatric Disorders in a National Sample of US Adolescents. *Archives of General Psychiatry*, *69*(11), 1151–1160. https://doi.org/10.1001/archgenpsychiatry.2011.2277

Michl, L. C., McLaughlin, K. A., Shepherd, K., & Nolen-Hoeksema, S. (2013). Rumination as a mechanism linking stressful life events to symptoms of depression and anxiety: Longitudinal evidence in early adolescents and adults. *Journal of Abnormal Psychology*, *122*(2), 339–352. https://doi.org/10.1037/a0031994

Monroe, M., Rohde, P., Seeley, J. R., & Lewinsohn, P. M. (1999). Life Events and Depression in Adolescence: Relationship Loss as a Prospective Risk Factor for First Onset of Major Depressive Disorder. *Journal of Abnormal Psychology*, *108*(4), 606–614.

Monroe, S. M., & Reid, M. W. (2008). Gene-Environment Interactions in Depression Research: Genetic Polymorphisms and Life-Stress Polyprocedures. *Psychological Science*, *19*(10), 947–956. https://doi.org/10.1111/j.1467-9280.2008.02181.x

Murberg, T. A., & Bru, E. (2005). The role of coping styles as predictors of depressive symptoms among adolescents: A prospective study. *Scandinavian Journal of Psychology*, *46*(4), 385–393. https://doi.org/10.1111/j.1467-9450.2005.00469.x

Murdock, K. K. (2013). Texting while stressed: Implications for students' burnout, sleep, and well-being. *Psychology of Popular Media Culture*, *2*(4), 207–221. https://doi.org/10.1037/ppm0000012

Nahum-Shani, I., Smith, S. N., Spring, B. J., Collins, L. M., Witkiewitz, K., Tewari, A., & Murphy, S. A. (2018). Just-in-Time Adaptive Interventions (JITAIs) in Mobile Health: Key Components and Design Principles for Ongoing Health Behavior Support. *Annals of Behavioral Medicine*, *52*(6), 446–462. https://doi.org/10.1007/s12160-016-9830-8

Nelson, E. E., Leibenluft, E., McClure, E. B., & Pine, D. S. (2005). The social re-orientation of adolescence: A neuroscience perspective on the process and its relation to psychopathology. *Psychological Medicine*, *35*(2).

Oh, H. J., Lauckner, C., Boehmer, J., Fewins-Bliss, R., & Li, K. (2013). Facebooking for health: An examination into the solicitation and effects of health-related social support on social networking sites. *Computers in Human Behavior*, *29*(5), 2072–2080. https://doi.org/10.1016/j.chb.2013.04.017

Orben, A., & Przybylski, A. K. (2019a). The association between adolescent well-being and digital technology use. *Nature Human Behaviour*, *3*(2), 173–182. https://doi.org/10.1038/s41562-018-0506-1

Orben, A., & Przybylski, A. K. (2019b). Screens, Teens, and Psychological Well-Being: Evidence From Three Time-Use-Diary Studies. *Psychological Science*, *30*(5), 682–696. https://doi.org/10.1177/0956797619830329

Padilla-Walker, L. M., Coyne, S. M., & Fraser, A. M. (2012). Getting a High-Speed Family Connection: Associations Between Family Media Use and Family Connection. *Family Relations*, *61*(3), 426–440. https://doi.org/10.1111/j.1741-3729.2012.00710.x

Paus, T., Keshavan, M., & Giedd, J. N. (2008). Why do many psychiatric disorders emerge during adolescence? *Nature Reviews Neuroscience*, *9*(12), 947–957. https://doi.org/10.1038/nrn2513

Pine, D. S., Cohen, P., Gurley, D., Brook, J., & Ma, Y. (1998). The Risk for Early-Adulthood Anxiety and Depressive Disorders in Adolescents With Anxiety and Depressive Disorders. *Archives of General Psychiatry*, *55*(1), 56–64. https://doi.org/10.1001/archpsyc.55.1.56

Potthoff, J. G., Holahan, C. J., & Joiner, T. E. (1995). Reassurance seeking, stress generation, and depressive symptoms: An integrative model. *Journal of Personality and Social Psychology*, *68*(4), 664–670. https://doi.org/10.1037/0022-3514.68.4.664

Prinstein, M. J., & Aikins, J. W. (2004). Cognitive Moderators of the Longitudinal Association Between Peer Rejection and Adolescent Depressive Symptoms. *Journal of Abnormal Child Psychology*, *32*(2), 147–158. https://doi.org/10.1023/B:JACP.0000019767.55592.63

Prinstein, M. J., Boergers, J., Spirito, A., Little, T. D., & Grapentine, W. L. (2000). Peer Functioning, Family Dysfunction, and Psychological Symptoms in a Risk Factor Model for Adolescent Inpatients' Suicidal Ideation Severity. *Journal of Clinical Child Psychology*, *29*(3), 392–405. https://doi.org/10.1207/S15374424JCCP2903_10

Prinstein, M. J., Borelli, J. L., Cheah, C. S. L., Simon, V. A., & Aikins, J. W. (2005). Adolescent Girls' Interpersonal Vulnerability to Depressive Symptoms: A Longitudinal Examination

of Reassurance-Seeking and Peer Relationships. *Journal of Abnormal Psychology*, *114*(4), 676–688. https://doi.org/10.1037/0021-843X.114.4.676

R Core Team. (2019). *R: A language and environment for statistical computing.* (3.5.2) [Computer software]. R Foundation for Statistical Computing.

Redmayne, M., Smith, E., & Abramson, M. J. (2013). The relationship between adolescents' well-being and their wireless phone use: A cross-sectional study. *Environmental Health*, *12*(1), 90. https://doi.org/10.1186/1476-069X-12-90

Rodman, A. M., Powers, K. E., & Somerville, L. H. (2017). Development of self-protective biases in response to social evaluative feedback. *Proceedings of the National Academy of Sciences*, *114*(50), 13158–13163. https://doi.org/10.1073/pnas.1712398114

Rose, A. J. (2002). Co-Rumination in the Friendships of Girls and Boys. *Child Development*, *73*(6), 1830–1843. https://doi.org/10.1111/1467-8624.00509

Roser, K., Schoeni, A., Foerster, M., & Röösli, M. (2016). Problematic mobile phone use of Swiss adolescents: Is it linked with mental health or behaviour? *International Journal of Public Health*, *61*(3), 307–315. https://doi.org/10.1007/s00038-015-0751-2

Saeb, S., Zhang, M., Karr, C. J., Schueller, S. M., Corden, M. E., Kording, K. P., & Mohr, D. C. (2015). Mobile Phone Sensor Correlates of Depressive Symptom Severity in Daily-Life Behavior: An Exploratory Study. *Journal of Medical Internet Research*, *17*(7), e175. https://doi.org/10.2196/jmir.4273

Saha, R., Huebner, E. S., Hills, K. J., Malone, P. S., & Valois, R. F. (2014). Social Coping and Life Satisfaction in Adolescents. *Social Indicators Research*, *115*(1), 241–252. https://doi.org/10.1007/s11205-012-0217-3

Sánchez-Martínez, M., & Otero, A. (2008). Factors Associated with Cell Phone Use in Adolescents in the Community of Madrid (Spain). *CyberPsychology & Behavior*, *12*(2), 131–137. https://doi.org/10.1089/cpb.2008.0164

Sano, A., Taylor, S., McHill, A. W., Phillips, A. J., Barger, L. K., Klerman, E., & Picard, R. W. (2018). Identifying Objective Physiological Markers and Modifiable Behaviors for Self-Reported Stress and Mental Health Status Using Wearable Sensors and Mobile Phones: Observational Study. *Journal of Medical Internet Research*, *20*(6), e210. https://doi.org/10.2196/jmir.9410

Schwartz-Mette, R. A., & Rose, A. J. (2012). Co-Rumination Mediates Contagion of Internalizing Symptoms within Youths' Friendships. *Developmental Psychology*, *48*(5), 1355–1365. https://doi.org/10.1037/a0027484

Sebastian, C., Viding, E., Williams, K. D., & Blakemore, S.-J. (2010). Social brain development and the affective consequences of ostracism in adolescence. *Brain and Cognition*, *72*(1), 134–145. https://doi.org/10.1016/j.bandc.2009.06.008

Sequeira, L., Battaglia, M., Perrotta, S., Merikangas, K., & Strauss, J. (2019). Digital Phenotyping With Mobile and Wearable Devices: Advanced Symptom Measurement in Child and Adolescent Depression. *Journal of the American Academy of Child & Adolescent Psychiatry*, *58*(9), 841–845. https://doi.org/10.1016/j.jaac.2019.04.011

Silk, J. S., Stroud, L. R., Siegle, G. J., Dahl, R. E., Lee, K. H., & Nelson, E. E. (2012). Peer acceptance and rejection through the eyes of youth: Pupillary, eyetracking and ecological data from the Chatroom Interact task. *Social Cognitive and Affective Neuroscience*, *7*(1), 93–105. https://doi.org/10.1093/scan/nsr044

Skierkowski, D., & Wood, R. M. (2012). To text or not to text? The importance of text messaging among college-aged youth. *Computers in Human Behavior*, *28*(2), 744–756. https://doi.org/10.1016/j.chb.2011.11.023

Sliwinski, M. J., Almeida, D. M., Smyth, J., & Stawski, R. S. (2009). Intraindividual change and variability in daily stress processes: Findings from two measurement-burst diary studies. *Psychology and Aging*, *24*(4), 828–840. https://doi.org/10.1037/a0017925

Somerville, L. H. (2013). The Teenage Brain: Sensitivity to Social Evaluation. *Current Directions in Psychological Science*, *22*(2), 121–127. https://doi.org/10.1177/0963721413476512

Somerville, L. H., Jones, R. M., Ruberry, E. J., Dyke, J. P., Glover, G., & Casey, B. J. (2013). The Medial Prefrontal Cortex and the Emergence of Self-Conscious Emotion in Adolescence. *Psychological Science*, *24*(8), 1554–1562. https://doi.org/10.1177/0956797613475633

Spitzer, R. L., Kroenke, K., Williams, J. B. W., & Löwe, B. (2006). A Brief Measure for Assessing Generalized Anxiety Disorder: The GAD-7. *Archives of Internal Medicine*, *166*(10), 1092–1097. https://doi.org/10.1001/archinte.166.10.1092

Stan Development Team. (2018). *The Stan Core Library* (2.18.0) [Computer software]. http://mc-stan.org

Stawski, R. S., Sliwinski, M. J., Almeida, D. M., & Smyth, J. M. (2008). Reported Exposure and Emotional Reactivity to Daily Stressors: The Roles of Adult-Age and Global Perceived Stress. *Psychology and Aging*, *23*(1), 52–61. https://doi.org/10.1037/0882-7974.23.1.52

Stice, E., Ragan, J., & Randall, P. (2004). Prospective Relations Between Social Support and Depression: Differential Direction of Effects for Parent and Peer Support? *Journal of Abnormal Psychology*, *113*(1), 155–159. https://doi.org/10.1037/0021-843X.113.1.155

Stroud, L. R., Foster, E., Papandonatos, G. D., Handwerger, K., Granger, D. A., Kivlighan, K. T., & Niaura, R. (2009). Stress response and the adolescent transition: Performance versus peer rejection stressors. *Development and Psychopathology*, *21*(1), 47–68. https://doi.org/10.1017/S0954579409000042

Thomée, S., Härenstam, A., & Hagberg, M. (2011). Mobile phone use and stress, sleep disturbances, and symptoms of depression among young adults—A prospective cohort study. *BMC Public Health*, *11*(1), 66. https://doi.org/10.1186/1471-2458-11-66

Torous, J., Kiang, M. V., Lorme, J., & Onnela, J.-P. (2016). New Tools for New Research in Psychiatry: A Scalable and Customizable Platform to Empower Data Driven Smartphone Research. *JMIR Mental Health*, *3*(2), e16. https://doi.org/10.2196/mental.5165

van Roekel, E., Keijsers, L., & Chung, J. M. (2019). A Review of Current Ambulatory Assessment Studies in Adolescent Samples and Practical Recommendations. *Journal of Research on Adolescence*, *29*(3), 560–577. https://doi.org/10.1111/jora.12471

Weeks, D. G., Michela, J. L., Peplau, L. A., & Bragg, M. E. (1980). Relation between loneliness and depression: A structural equation analysis. *Journal of Personality and Social Psychology*, *39*(6), 1238–1244. https://doi.org/10.1037/h0077709

Weinstein, E. C., & Selman, R. L. (2016). Digital stress: Adolescents' personal accounts. *New Media & Society*, *18*(3), 391–409. https://doi.org/10.1177/1461444814543989

Williams, K. D. (2007). Ostracism. *Annual Review of Psychology*, *58*(1), 425–452. https://doi.org/10.1146/annurev.psych.58.110405.085641

Zawadzki, M. J., Scott, S. B., Almeida, D. M., Lanza, S. T., Conroy, D. E., Sliwinski, M. J., Kim, J., Marcusson-Clavertz, D., Stawski, R. S., Green, P. M., Sciamanna, C. N., Johnson, J. A., & Smyth, J. M. (2019). Understanding stress reports in daily life: A coordinated analysis of factors associated with the frequency of reporting stress. *Journal of Behavioral Medicine*, *42*(3), 545–560. https://doi.org/10.1007/s10865-018-00008-x

Supplemental Materials

to accompany

A year in the social life of a teenager: Within-person fluctuations in stress, phone communication, and anxiety and depression

Rodman, Vidal Bustamante, Dennison, Flournoy,

Coppersmith, Nook, Worthington, Mair & McLaughlin

Supplemental Materials

Data quality and participant retention

The current study had excellent participant retention rates, with only 5 missed visits out of 360 (98.61% retention rate). Each of these missed visits occurred for different participants. Nonetheless, the analysis approach used in the current paper estimates parameters using all available Level-1 data (i.e., repeated assessments of participants over time), does not require all participants to have identical or balanced observations at Level-1, and permits examination of between- and within-person components of variance in predictors and outcomes (Raudenbush & Bryk, 2002). In addition to these missed visits, there were circumstantial and technical challenges that resulted in loss of phone communication data. Two participants did not provide any phone call or text messaging data and two participants did not provide any text messaging data. The remaining instances of missing phone or text data are presented in Table S6. In the rare cases when survey questionnaires had missing responses to questions due to technical error (GAD-7 missing 2 responses out of 2485 possible responses; PHQ-9 missing 14 out of 3195 possible responses), response values were imputed with the average score of the participant's remaining questions for that month and rounded to the nearest integer.

As stated in the main text, due to technical issues, it is impossible to compute exactly how many momentary assessments were erroneously unsent or simply skipped by participants. However, if all planned prompts had reached participants, they would have a maximum of 7,560 prompts. As such, participants completed more than 65% of all possible prompts, despite these technical issues, which is a rate that is standard for this sampling approach (van Roekel et al., 2019).

Simulation Power Analysis

To test our ability to detect within-person effects (the focus of our study), we conducted statistical power simulations based on the distribution, mean, and dispersion of our variables of interest. We tested statistical power to detect small (standardized beta = 0.11), medium (standardized beta = 0.3), and large effect sizes (standardized beta = 0.5) for associations between stressful life events (SLEs) and phone communication, and between phone communication and internalizing symptoms. Our simulations assumed 11 observations per participant and evaluated sample sizes from 5 to 50 participants. Results revealed that with 30 participants (11 observations each; collection of phone call data began *after* the first visit) we were well-powered (>80%) to detect small (as small as standardized beta = 0.11), medium, and large within-person effects for our variables of interest (Figure S4). In fact, we were powered at 98% to detect effects as small as standardized beta = 0.15. It is important to note that while all analyses presented in our manuscript were conducted using a Bayesian approach, our power analyses were conducted using a standard frequentist approach, given that statisticians have not come to a consensus regarding the meaning of power in a Bayesian context (in Bayesian analysis all the focus is on estimation and not on testing), and much less regarding a standard way of computing statistical power akin to the frequentist way commonly used in psychology studies.

Model specification procedures and control analyses

Posterior predictive checks showed that for all models, Gaussian model specification captured the data well; however, a small proportion of predicted values fell below zero, which is impossible for clinical symptom sum scores or phone count data. Because the objective of these models was for explanatory and not predictive purposes, Gaussian models are appropriate for our

current analyses. In addition, multi-level mediation effects are challenging to estimate when using varied and complex, non-linear models, such as those with negative binomial errors, wherein the parameter estimates of path models are on different scales. The use of path models with Gaussian specification in our Bayesian mediation models made estimation more tractable. Nonetheless, it is possible that other distribution specifications may fit the data even better than the Gaussian modelling approach, which we explored as a complementary analysis. When examining the monthly-level models with depression and anxiety symptoms as outcomes, sum scores were transformed into proportions scores out of maximum possible scores and Bayesian hierarchical models were re-computed using a beta distribution specification, which is suitable for proportion data (Smithson & Verkuilen, 2006). Monthly-level models examining phone call and text behaviors as outcomes, models were computed using total count data (i.e., total number of phone calls or texts in a month instead of a daily average) and log-transformed offset of days between study visits, with a negative binomial model specification, appropriate for count-generated data that are non-negative, integers, contain zeros, and are right skewed (Hilbe, 2011). Momentary-level analyses were re-computed using a negative binomial distribution, which was the best non-gaussian fit of the data for all momentary-level models. After re-estimating each separate hierarchical model, we confirmed that the general pattern and magnitude of associations across all monthly and momentary-level models were similar to all models using the Gaussian specification reported in the main document (see Table S3). All code and data are posted to Open Science Framework and can be accessed at https://osf.io/nhfsc/.

Robust sensitivity analyses

We undertook additional sensitivity analyses by computing key monthly level models with robust (Student's *t* distribution) model specification using the package *brms* in R (Bürkner,

2017). After re-estimating each separate hierarchical model, we confirmed that the general pattern and magnitude of associations of key findings described in the main document held (see Table S9).

Chronic Stress

Chronic stress occurring in the past month was assessed at each study visit using the UCLA Life Stress Interview (Hammen, 1988), a semi-structured interview designed to objectively measure the impact of both episodic and chronic stress (e.g., ongoing conflict in the home, long-term medical issues). Chronic stress for each domain (i.e., peers, parents, household/extended family, neighborhood, school, academic, health, finance, and discrimination) was objectively coded on a 9-point scale ranging from 1 (none) to 5 (extremely severe), including half-points. These values were transformed to an integer scale from 0-8 and the severity score for the domain coded as the highest severity for each month was used for analysis (Table 1, Figure S1).

Examination of the relationship between chronic stress and psychopathology or social communication were conducted in the same way analyses were completed for SLEs in the main document (Table S2). Examination of the relationship between chronic stress and anxiety and depression revealed that within-person fluctuations in chronic stress were not associated with changes in anxiety or depression symptoms either concurrently or in the following month. Within-person increases in chronic stress were, however, associated with increased outgoing and incoming phone calls during the same month and the following month, as well as fewer received text messages during the same month, but not the following month.

Co-rumination

In order to characterize the relationships between phone communication and stress or clinical symptoms, we examined co-rumination as a potential maladaptive social behavior that may help explain the interpersonal and psychological mechanisms at play. Co-rumination is a stress-related communication style that involves repeated and fixated discussion of stressors with others and contributes to negative mental health outcomes (Rose, 2002). Co-rumination was measured at each monthly visit using the Co-Rumination Questionnaire (Short Form), a 9-item self-report measure designed to assess the extent to which participants engage in or attempt to engage in co-rumination with close friends over problems or stressful events. An example item is: "When my friend and I talk about a problem that I have we try to figure out everything about the problem, even if there are parts that we may never understand." Items are scored from 1 to 5 with higher scores indicating greater tendency of co-rumination. The CRQ-Short has good reliability and validity (Rose, 2002) and excellent internal consistency across all time points in the current study (α=.87-.97; ICC=.684).

Given the relationships between increases in phone communication and worsening of clinical symptoms, co-rumination was investigated as a possible interpersonal factor that could explain these associations. All models were analyzed using the same method described in the main manuscript document. When examining its relation to SLEs, we found that within-person fluctuations in SLEs were not related to concurrent or subsequent changes in reports of co-rumination. When examining whether co-rumination was associated with phone communication, however, findings revealed that more co-rumination than usual was associated with increased incoming phone calls during the same month, but showed no association with other phone indices or with phone communication the following month. As expected, we found that co-rumination was associated with internalizing symptoms. Specifically, greater within-person

increases in reported co-rumination was associated with anxiety in the same month and depression in the following month (Table S5). While not associated with stress, co-rumination may be a contributing factor that could help explain why increases in incoming phone calls following stress leads to an increase in symptoms of anxiety. Tracking of social communication, captured here by text messages and phone calls, could represent a stress-related marker of clinical risk that reflects complex social and psychological factors, that may include co-ruminative behaviors.

Length of Communication

Additional analyses examining the relationships between length of phone call or text communication and stress or symptoms of anxiety and depression were conducted using the same modeling approach conducted for primary analyses in the main document. These findings indicated that duration of calls and length of text messages were not significantly related to stress or psychopathology, with the exception of outgoing call length, which was only weakly related to concurrent symptoms of depression. (Table S7). Thus, frequency of communication remains the key marker of risk for psychopathology following stress. One possible explanation is that experiences of stress and worry are associated with the behavior of engaging in communication itself rather than other qualitative features, such as duration of communication, and is thus more strongly related to risk for psychopathology.

Interpersonal Stress

Interpersonal stress occurring in the past month was assessed at each study visit using the UCLA Life Stress Interview (Hammen, 1988), a semi-structured interview designed to objectively measure the impact of episodic stress for each domain related to interpersonal relationships (i.e., peers, parents, household/extended family). Items were objectively coded on a

9-point scale ranging from 1 (none) to 5 (extremely severe), including half-points. These values were transformed to an integer scale from 0-8 and the severity score for the domain coded as the highest severity for each month was used for analysis. Examination of the relationship between interpersonal stress and psychopathology or social communication were conducted in the same way analyses were completed for general SLEs in the main document. Overall, findings using interpersonal SLEs were very similar to key findings described in the main document (Table S10). Examination of the relationship between interpersonal stress and anxiety and depression revealed that within-person fluctuations in interpersonal stress were not associated with changes in anxiety or depression symptoms either concurrently or in the following month. Within-person increases in interpersonal stress were, however, associated with greater frequency of outgoing and incoming calls during the same month, as well as increased incoming calls the following month.

Supplemental Figures and Tables

Supplemental Table 1

Compensation Schedule

Month	Visit Lenth (approx.)	Earnings
1	180 minutes	$ 50.00
2	90 minutes	$ 30.00
3	90 minutes	$ 40.00
4	90 minutes	$ 50.00
5	90 minutes	$ 60.00
6	90 minutes	$ 70.00
7	90 minutes	$ 80.00
8	90 minutes	$ 90.00
9	90 minutes	$ 100.00
10	90 minutes	$ 110.00
11	90 minutes	$ 125.00
12	180 minutes	$ 100.00
	Total	$ 905.00

Supplemental Table 2

Table S2. Bayesian hierarchical model outcomes examining the effect of chronic stress

	Within-person effects (concurrent)			Within-person effects (lagged)		
Model	*B*	*SE*	*95% CR*	*B*	*SE*	*95% CR*
Chronic Stress predicting						
Generalized Anxiety (GAD-7)	0.091	0.127	[-0.154, 0.336]	0.185	0.136	[-0.085, 0.451]
Depression (PHQ-9)	0.078	0.134	[-0.193, 0.330]	0.165	0.140	[-0.114, 0.439]
Chronic Stress predicting						
Outgoing Calls	0.247	0.090	**[0.065, 0.421]**	0.316	0.093	**[0.132, 0.503]**
Incoming Calls	0.192	0.071	**[0.049, 0.332]**	0.340	0.073	**[0.198, 0.491]**
Outgoing Texts	-1.039	1.157	[-3.335, 1.401]	-0.359	1.201	[-2.807, 2.019]
Incoming Texts	-2.856	1.372	**[-5.564, -0.242]**	-1.659	1.425	[-4.448, 1.089]

Note: B = unstandardized coefficient; SE = standard error of coefficient; CR = 95% credible interval (15,000 samples); Bold denotes significant effect. All models included study visit number and whether school was in sessio as nuissance regressors.

Supplemental Table 3

Table S3. Bayesian hierarchical model outcomes at monthly level using Beta or Negative Binomial model specification

Monthly Level	Within-person effects (concurrent)			Within-person effects (lagged)		
Model	*B*	*SE*	*95% CR*	*B*	*SE*	*95% CR*
Stressful Life Events predicting						
Generalized Anxiety (GAD-7)	0.038	0.013	**[0.012, 0.064]**	0.005	0.015	[-0.024, 0.034]
Depression (PHQ-9)	0.016	0.011	[-0.005, 0.038]	0.025	0.012	**[0.001, 0.049]**
Stressful Life Events predicting						
Outgoing Calls	0.043	0.010	**[0.022, 0.063]**	0.028	0.011	**[0.006, 0.049]**
Incoming Calls	0.021	0.010	**[0.001, 0.041]**	0.021	0.010	**[0.001, 0.041]**
Outgoing Texts	0.005	0.012	[-0.018, 0.028]	0.000	0.012	[-0.022, 0.024]
Incoming Texts	0.009	0.012	[-0.015, 0.033]	0.004	0.012	[-0.019, 0.027]
Outgoing Calls predicting						
Generalized Anxiety (GAD-7)	0.042	0.029	[-0.014, 0.098]	0.032	0.030	[-0.027, 0.096]
Depression (PHQ-9)	0.032	0.024	[-0.012, 0.078]	0.023	0.026	[-0.032 0.076]
Incoming Calls predicting						
Generalized Anxiety (GAD-7)	0.074	0.033	**[0.010, 0.142]**	0.103	0.037	**[0.028, 0.177]**
Depression (PHQ-9)	0.037	0.028	[-0.022, 0.093]	0.044	0.033	[-0.020, 0.108]
Outgoing Texts predicting						
Generalized Anxiety (GAD-7)	0.003	0.002	[-0.002, 0.008]	0.001	0.003	[-0.005, 0.007]
Depression (PHQ-9)	0.003	0.002	[-0.001, 0.007]	0.000	0.002	[-0.006, 0.004]
Incoming Texts predicting						
Generalized Anxiety (GAD-7)	0.002	0.002	[-0.002, 0.006]	0.001	0.002	[-0.004, 0.006]
Depression (PHQ-9)	0.004	0.002	**[0.001, 0.007]**	0.000	0.002	[-0.004, 0.005]
Momnetary Level	Morning → afternoon (lagged)			Afternoon → evening (lagged)		
Model	*B*	*SE*	*95% CR*	*B*	*SE*	*95% CR*
EMA Stress predicting						
EMA Anxiety	0.035	0.014	**[0.008, 0.064]**	0.045	0.013	**[0.021, 0.072]**
EMA Depression	0.017	0.017	[-0.017, 0.050]	0.031	0.016	**[0.001, 0.062]**
EMA Stress predicting						
Outgoing Calls	-0.001	0.048	[-0.095, 0.088]	-0.008	0.038	[-0.085, 0.063]
Incoming Calls	0.091	0.041	**[0.011, 0.169]**	-0.006	0.039	[-0.081, 0.073]
Outgoing Texts	-0.049	0.032	[-0.111, 0.012]	0.004	0.032	[-0.056, 0.067]
Incoming Texts	-0.022	0.029	[-0.079, 0.037]	0.017	0.031	[-0.039, 0.081]
Outgoing Calls predicting						
EMA Anxiety	0.024	0.020	[-0.017, 0.063]	-0.005	0.010	[-0.025, 0.015]
EMA Depression	0.016	0.026	[-0.032, 0.066]	0.005	0.012	[-0.018, 0.028]
Incoming Calls predicting						
EMA Anxiety	0.009	0.026	[-0.040, 0.064]	-0.015	0.019	[-0.049, 0.022]
EMA Depression	-0.011	0.030	[-0.073, 0.048]	-0.028	0.022	[-0.070, 0.014]
Outgoing Texts predicting						
EMA Anxiety	0.000	0.002	[-0.003, 0.004]	0.000	0.001	[-0.002, 0.003]
EMA Depression	0.000	0.002	[-0.004, 0.004]	0.001	0.001	[-0.002, 0.003]
Incoming Texts predicting						
EMA Anxiety	0.001	0.002	[-0.003, 0.004]	0.001	0.001	[-0.001, 0.003]
EMA Depression	0.001	0.002	[-0.003, 0.005]	0.000	0.001	[-0.002, 0.003]

Note: Statistics reflect outcome of within-person effects. B = unstandardized coefficient; SE = standard error of coefficient; CR = 95% credible interval (15,000 samples); Bold denotes significant effect.

Supplemental Table 4

Table S4. Bayesian within-person mediation model outcomes

	Proportion mediated	*95% CR*	*Indirect effect*	*95% CR*	*a path*	*b path*
Concurrent mediation models						
SLEs ➤ Outgoing Calls ➤ Depression	**42.68%**	**[6.82%, 96.32%]**	**0.029**	**[0.0004, 0.065]**	0.142	0.215
SLEs ➤ Outgoing Calls ➤ Anxiety	28.89%	[0.01%, 81.22%]	0.028	[-0.001, 0.061]	0.142	0.203
SLEs ➤ Incoming Calls ➤ Anxiety	20.07%	[0.003%, 70.94%]	0.019	[-0.0003, 0.044]	0.078	0.257
Prospective mediation models						
SLEs ➤ Incoming Calls ➤ Anxiety +1 month	**39.38%**	**[10.60%, 90.99%]**	**0.035**	**[0.009, 0.068]**	0.078	0.469
SLEs ➤ Incoming Calls +1 month ➤ Anxiety +2 months	**38.70%**	**[6.96%, 91.69%]**	**0.030**	**[0.005, 0.062]**	0.069	0.457

Note: Predictor ➤ Mediator ➤ Outcome; CR = Credible Interval; Bold denotes significant effect. All models were run controlling for study visit and whether school was in session.

Supplemental Table 5

Table S5. Bayesian hierarchical model outcomes examining Co-rumination

	Within-person effects (concurrent)			Within-person effects (lagged)		
Model	*B*	*SE*	*95% CR*	*B*	*SE*	*95% CR*
Episodic Stress predicting						
Co-rumination	0.021	0.092	[-0.159, 0.208]	0.181	0.099	[-0.017, 0.372]
Co-rumination predicting						
Outgoing Calls	0.033	0.019	[-0.006, 0.071]	0.003	0.019	[-0.035, 0.040]
Incoming Calls	0.045	0.016	**[0.014, 0.075]**	-0.007	0.015	[-0.037, 0.024]
Outgoing Texts	0.266	0.253	[-0.250, 0.754]	0.214	0.249	[-0.292, 0.705]
Incoming Texts	-0.002	0.299	[-0.587, 0.594]	-0.015	0.294	[-0.595, 0.567]
Co-rumination predicting						
Generalized Anxiety (GAD-7)	0.080	0.027	**[0.029, 0.133]**	0.044	0.029	[-0.013, 0.100]
Depression (PHQ-9)	0.051	0.028	[-0.002, 0.107]	0.058	0.029	**[0.001, 0.115]**

Note: B = unstandardized coefficient; SE = standard error of coefficient; CR = 95% credible interval (15,000 samples
Bold denotes significant effect. All models included study visit number and whether school was in session as nuissance regressors.

Supplemental Table 6

Table S6. Missing phone communication data by month

Month	Text Message Data	Phone Call Data
1	NA	NA
2	1	0
3	3	3
4	2	1
5	1	0
6	1	2
7	0	1
8	1	1
9	1	2
10	2	2
11	1	1
12	2	1

Supplemental Table 7

Table S7. Bayesian hierarchical model outcomes for call and text length

Monthly Level	Within-person effects (concurrent)			Within-person effects (lagged)		
Model	*B*	*SE*	*95% CR*	*B*	*SE*	*95% CR*
Stressful Life Events predicting						
Outgoing Call Length (sec)	5.075	4.609	[-3.786, 14.248]	-1.025	4.678	[-10.093, 8.090]
Incoming Call Length (sec)	4.699	5.972	[-6.951, 16.379]	-2.473	6.046	[-14.265, 9.270]
Outgoing Text Length (char)	2.460	7.795	[-12.916, 17.467]	-1.735	7.979	[-17.281, 13.994]
Incoming Text Length (char)	3.884	8.125	[-12.161, 19.565]	-0.357	8.228	[-16.665, 15.631]
Outgoing Call Length predicting						
Generalized Anxiety (GAD-7)	0.001	0.001	[-0.0001, 0.002]	-0.0001	0.001	[-0.001, 0.001]
Depression (PHQ-9)	0.001	0.001	**[0.000, 0.002]**	-0.0001	0.001	[-0.001, 0.001]
Incoming Call Length predicting						
Generalized Anxiety (GAD-7)	0.001	0.0001	[-0.0001, 0.001]	-0.0001	0.0001	[-0.001, 0.001]
Depression (PHQ-9)	0.001	0.0001	[-0.0001, 0.002]	-0.0001	0.0001	[-0.001, 0.001]
Outgoing Text Length predicting						
Generalized Anxiety (GAD-7)	-0.0001	0.0001	[-0.0001, 0.001]	-0.0001	0.0001	[-0.0001, 0.001]
Depression (PHQ-9)	0.0001	0.0001	[-0.0001, 0.001]	-0.0001	0.0001	[-0.001, 0.001]
Incoming Text Length predicting						
Generalized Anxiety (GAD-7)	0.0001	0.0001	[-0.0001, 0.001]	0.0001	0.0001	[-0.0001, 0.001]
Depression (PHQ-9)	0.0001	0.0001	[-0.0001, 0.001]	0.0001	0.0001	[-0.0001, 0.001]

Note: Statistics reflect outcome of within-person effects. B = unstandardized coefficient; SE = standard error of coefficient; CR = 95% credible interval (15,000 samples); sec = seconds per day, char = characters per day; Bold denotes significant effect.

Supplemental Table 8

Table S8. Descriptive statistics and ICCs for length of phone communication

Dependent variable	*N*	*n*	*M*	*SD*	Range	Possible Range	ICC
Length of Outgoing Calls (seconds per day)	28	294	45.46	53.60	1-327	N/A	0.486
Length of Incoming Calls (seconds per day)	28	294	48.97	70.06	1-449.69	N/A	0.485
Length of Outgoing Texts (characters per day)	26	268	37.45	15.41	12.40-96.45	N/A	0.835
Length of Incoming Texts (characters per day)	26	275	38.17	11.81	14.53-81.38	N/A	0.813

Note: N = number of subjects, n = number of observations, M = mean, SD = standard deviation, ICC = intra-class correlation

Supplemental Table 9

Table S9. Bayesian hierarchical model outcomes using robust model specification

Monthly Level	Within-person effects (concurrent)			Within-person effects (lagged)		
Model	*B*	*SE*	*95% CR*	*B*	*SE*	*95% CR*
Stressful Life Events predicting						
Generalized Anxiety (GAD-7)	0.116	0.046	**[0.026, 0.207]**	0.025	0.049	[-0.072, 0.122]
Depression (PHQ-9)	0.092	0.047	[-0.0001, 0.185]	0.122	0.053	**[0.019, 0.225]**
Stressful Life Events predicting						
Outgoing Calls	0.033	0.016	**[0.001, 0.065]**	0.046	0.017	**[0.013, 0.079]**
Incoming Calls	0.010	0.010	[-0.009, 0.029]	0.023	0.009	**[0.004, 0.041]**
Outgoing Texts	0.097	0.170	[-0.235, 0.431]	0.179	0.183	[-0.187, 0.530]
Incoming Texts	0.101	0.199	[-0.293, 0.492]	-0.077	0.238	[-0.553, 0.377]
Outgoing Calls predicting						
Generalized Anxiety (GAD-7)	0.204	0.106	[-0.005, 0.408]	0.045	0.115	[-0.178, 0.274]
Depression (PHQ-9)	0.248	0.119	**[0.016, 0.482]**	0.130	0.106	[-0.074, 0.339]
Incoming Calls predicting						
Generalized Anxiety (GAD-7)	0.255	0.117	**[0.027, 0.488]**	0.416	0.129	**[0.156, 0.665]**
Depression (PHQ-9)	0.274	0.125	**[0.018, 0.507]**	0.208	0.125	[-0.039, 0.455]
Outgoing Texts predicting						
Generalized Anxiety (GAD-7)	0.011	0.008	[-0.005, 0.026]	0.005	0.010	[-0.016, 0.024]
Depression (PHQ-9)	0.010	0.009	[-0.007, 0.027]	-0.002	0.010	[-0.021, 0.017]
Incoming Texts predicting						
Generalized Anxiety (GAD-7)	0.010	0.006	[-0.002, 0.022]	0.004	0.007	[-0.011, 0.018]
Depression (PHQ-9)	0.012	0.007	[-0.001, 0.026]	0.003	0.007	[-0.011, 0.018]

Note: Statistics reflect outcome of within-person effects. B = unstandardized coefficient; SE = standard error of coefficient; CR = 95% credible interval (15,000 samples); Bold denotes significant effect.

Supplemental Table 10

Table S10. Bayesian hierarchical model outcomes with interpersonal stress

Monthly Level	Within-person effects (concurrent)			Within-person effects (lagged)		
Model	*B*	*SE*	*95% CR*	*B*	*SE*	*95% CR*
Interpersonal Stress predicting						
Generalized Anxiety (GAD-7)	0.142	0.086	[-0.026, 0.308]	0.007	0.090	[-0.170, 0.181]
Depression (PHQ-9)	0.060	0.090	[-0.118, 0.234]	0.076	0.094	[-0.108, 0.259]
Interpersonal Stress predicting						
Outgoing Calls	0.172	0.061	**[0.049, 0.290]**	0.095	0.060	[-0.022, 0.213]
Incoming Calls	0.137	0.049	**[0.042, 0.234]**	0.154	0.047	**[0.063, 0.248]**
Outgoing Texts	1.149	0.774	[-0.361, 2.660]	0.480	0.775	[-1.063, 1.981]
Incoming Texts	1.125	0.941	[-0.775, 2.924]	0.947	0.915	[-0.798, 2.798]

Note: Statistics reflect outcome of within-person effects. B = unstandardized coefficient; SE = standard error of coefficient; CR = 95% credible interval (15,000 samples); Bold denotes significant effect.

Supplemental Figure 1

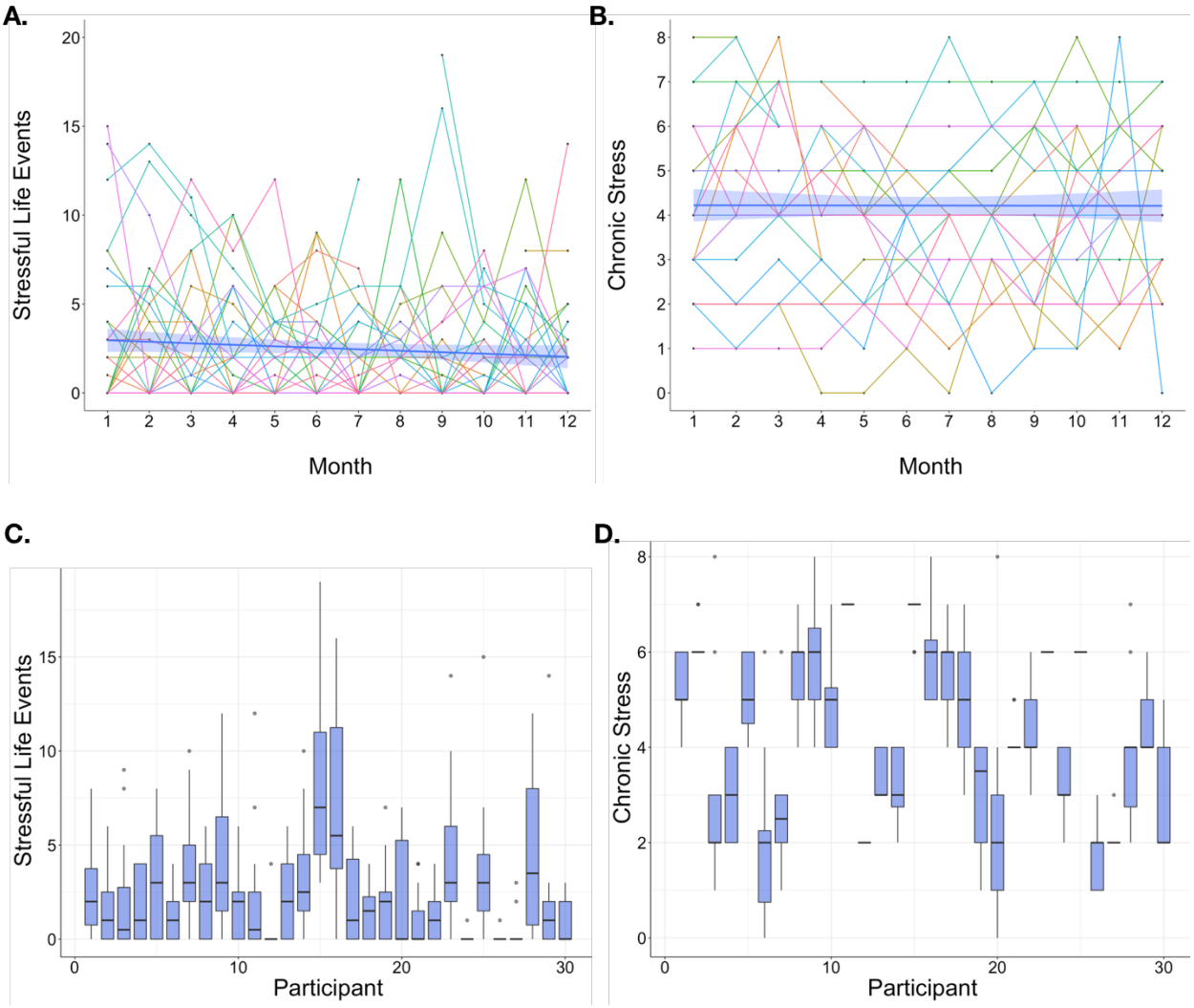


Figure S1. Variation in SLEs and chronic stressors over time and across participants. Spaghetti plots depict SLEs (A) and chronic stress severity (B) across the course of the 12-month study period, wherein each subject is represented by a different colored line. Blue line with shading indicates group average with 95% Confidence Interval. Box plots depict SLEs (C) and Chronic Stress (D) by participant.

Supplemental Figure 2

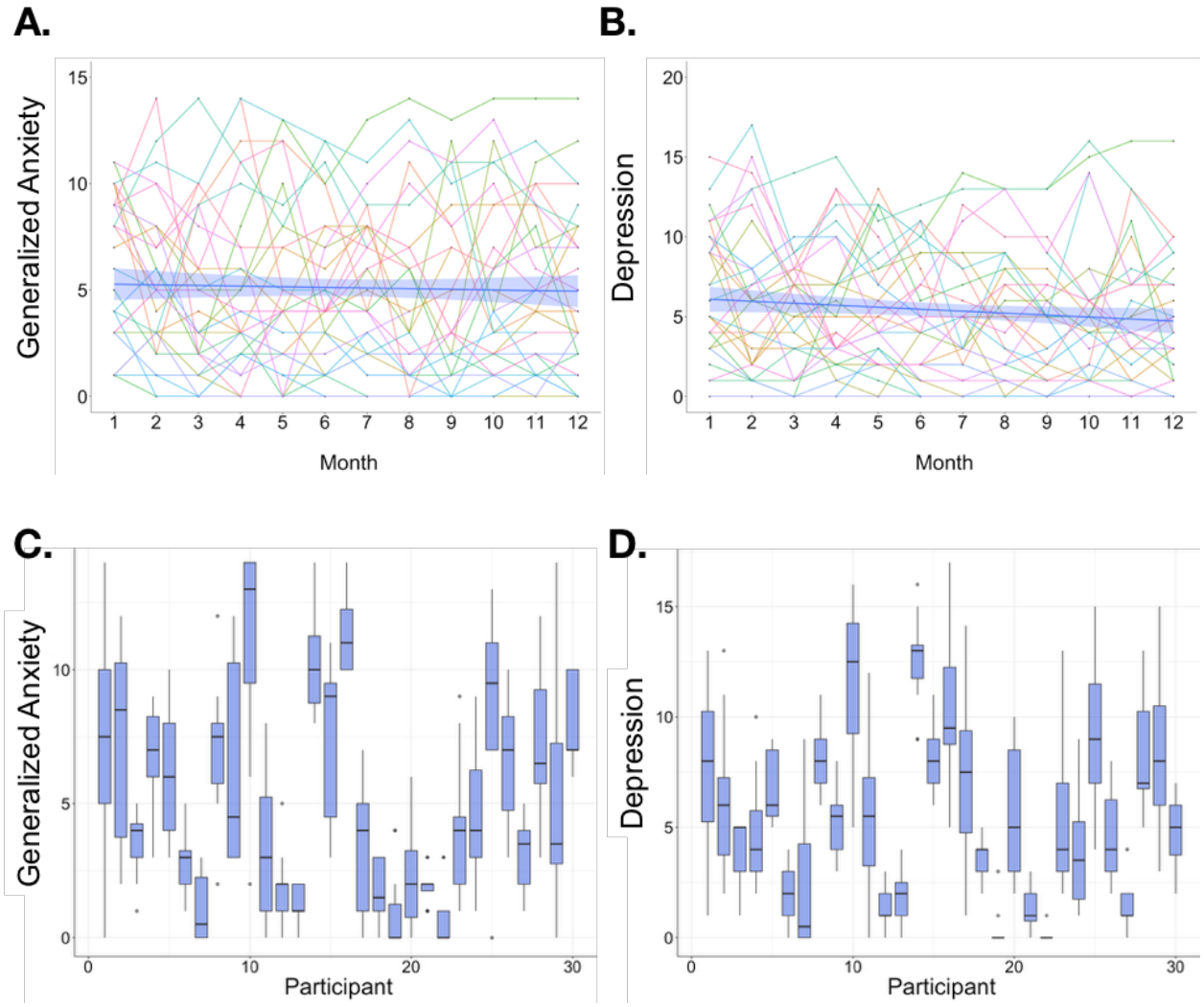
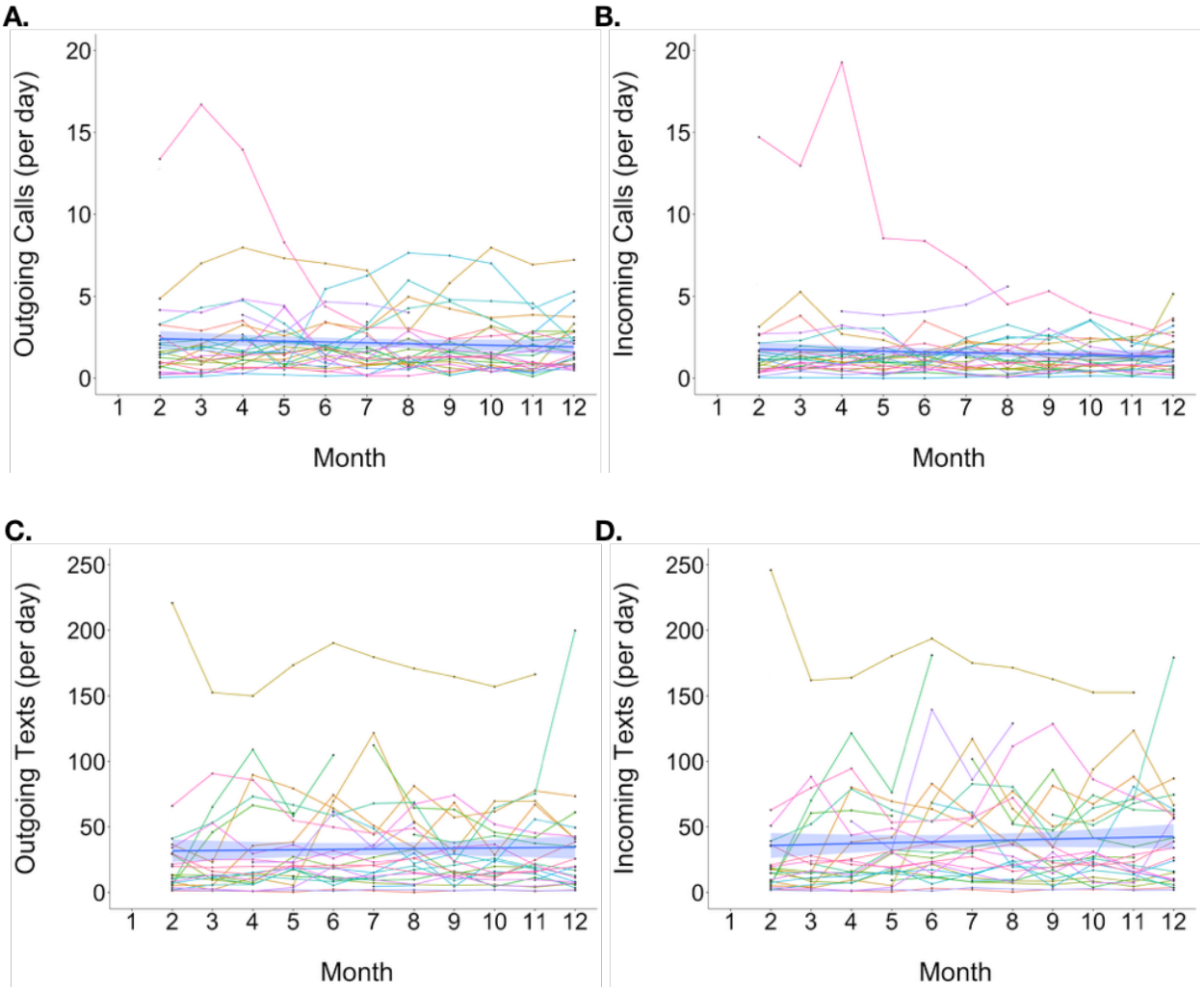


Figure S2. Variation in internalizing symptoms over time and across participants. Spaghetti plots show generalized anxiety measured by the GAD-7 (A) and depression measured by the PHQ-9 (B) across the course of the 12-month study period, wherein each subject is represented by a different colored line. Blue line with shading indicates group average with 95% Confidence Interval. Box plots depict generalized anxiety (C) and depression (D) by participant.

Supplemental Figure 3



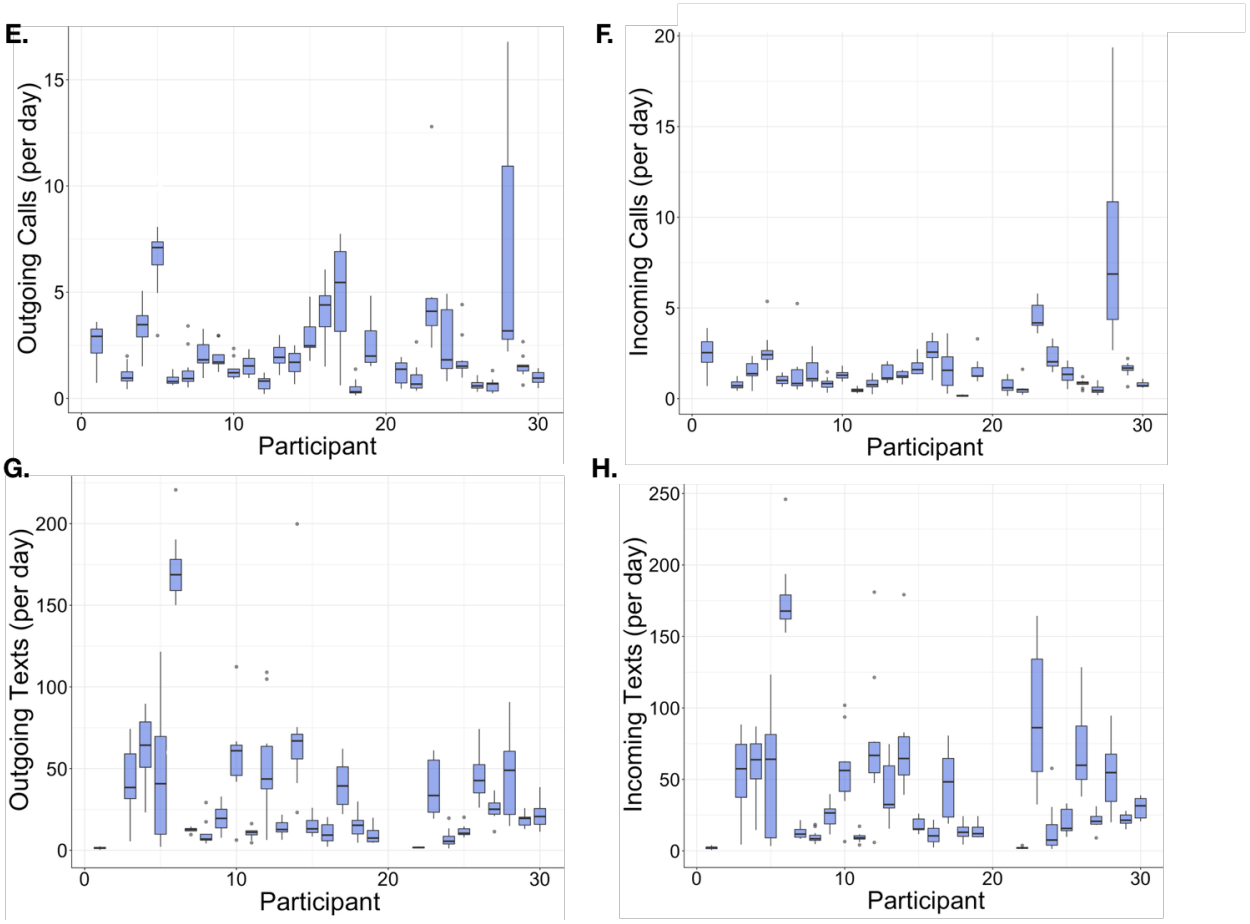


Figure S3. Phone communication over time. Spaghetti plots show frequency of outgoing calls (A) incoming calls (B) outgoing texts (C) incoming texts (D) across the course of the 12-month study period, wherein each subject is represented by a different colored line. Blue line with shading indicates group average with 95% Confidence Interval. Box plots depict frequency of outgoing calls (E), incoming calls (F), outgoing texts (G), and incoming texts (H) by participant.

Supplemental Figure 4

Figure S4. Line plot shows the results of statistical power simulation analyses for within-person effects. Power estimates are presented as a function of increasing number of participants (assuming 11 observations per participant). The orange line shows power estimates for small effects (standardized beta = 0.11), and the blue line shows power estimates for medium effects (standardized beta = 0.30). The horizontal dashed line marks the 80% power threshold, and the vertical dashed line shows our study's actual sample size (N=30 participants).

References:

Bürkner, P.-C. (2017). brms: An R Package for Bayesian Multilevel Models Using Stan. *Journal of Statistical Software*, *80*(1). https://doi.org/10.18637/jss.v080.i01

Hammen, C. (1988). Self-cognitions, stressful events, and the prediction of depression in children of depressed mothers. *Journal of Abnormal Child Psychology*. https://doi.org/10.1007/BF00913805

Hilbe, J. M. (2011). *Negative Binomial Regression*. Cambridge University Press.

Raudenbush, S. W., & Bryk, A. S. (2002). *Hierarchical Linear Models: Applications and Data Analysis Methods*. SAGE.

Rose, A. J. (2002). Co-Rumination in the Friendships of Girls and Boys. *Child Development*, *73*(6), 1830–1843. https://doi.org/10.1111/1467-8624.00509

Smithson, M., & Verkuilen, J. (2006). A better lemon squeezer? Maximum-likelihood regression with beta-distributed dependent variables. *Psychological Methods*, *11*(1), 54–71. https://doi.org/10.1037/1082-989X.11.1.54

van Roekel, E., Keijsers, L., & Chung, J. M. (2019). A Review of Current Ambulatory Assessment Studies in Adolescent Samples and Practical Recommendations. *Journal of Research on Adolescence*, *29*(3), 560–577. https://doi.org/10.1111/jora.12471