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Research paper

Characterizing the momentary association between loneliness, depression, and social interactions: Insights from an ecological momentary assessment study

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ABSTRACT

Evidence suggests that loneliness causes people to feel more depressed. It is unknown, however, why this association occurs and whether momentary versus chronic experiences of loneliness are implicated. Theoretical accounts suggest that momentary feelings of loneliness produce two competing motivations: social reaffiliation and social withdrawal. Social affiliation is protective against depression; social withdrawal, in contrast, is a risk factor. Thus, engaging in frequent and high-quality interactions following experiences of loneliness may protect against subsequent depression. We tested this hypothesis using a random-interval experience sampling design (5x/day/day, 14 days; *Nobs* = 6568) with a racially/ethnically diverse sample of adults with elevated depression symptoms ($N = 102$). Momentary loneliness was associated with depressed mood at the same time point and ~2.5h and ~5h later. Frequency and quality of social interaction did not moderate these associations. Findings suggest that momentary feelings of loneliness may be an important target for clinical intervention.

1. Introduction

Evidence of the public health significance of loneliness is growing. Rates of loneliness are increasing over time, especially in younger individuals (Buecker et al., 2021; Xin and Xin, 2016), and meta-analytic evidence from dozens of studies across more than 70,000 participants shows that lonely people die younger than non-lonely people (Holt-Lunstad et al., 2015; Rico-Uribe et al., 2018). As such, governments across the globe are calling for national strategies to reduce loneliness and social isolation (Office of the U.S. Surgeon General, 2023; UK Department for Culture, Media, and Sport, 2018).

Loneliness – the subjective feeling of being socially isolated – is a transdiagnostic risk factor for poor health (Christiansen et al., 2021; Nuyen et al., 2020). Perhaps most notably in this literature is the association between loneliness and depression. Lonely people tend to be more depressed than non-lonely people (Erzen and Çikrikci, 2018), and evidence across longitudinal studies suggests that loneliness may precede experiences of depression. For example, loneliness is prospectively associated with depression in clinical (van Beljouw et al., 2010) and non-clinical (Cacioppo et al., 2010; McHugh Power et al., 2020) samples, precedes the onset of clinical depression several years later (Beutel et al., 2017; Sjöberg et al., 2013; van Winkel et al., 2017), and hinders recovery from depression in already-depressed samples (Holvast et al., 2015; Luoma et al., 2015). Similar findings are observed in child and adolescent samples (Adam et al., 2011; Brière et al., 2018; Goosby et al., 2013; Yang et al., 2018).

To understand whether loneliness may cause depression (or vice versa), Sbarra et al. (2023) used a quasi-experimental analytic method called Mendelian randomization (Sanderson et al., 2022) with a sample of 511,280 participants. Their analysis revealed robust evidence of a bidirectional causal relationship, lending support to the notion that reducing loneliness may help decrease risk for depression. However, although reducing loneliness may be a viable depression intervention target, there is little evidence that speaks to the strategies needed to

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effectively intervene. In other words, myriad studies have established that people who are lonelier tend to be more depressed, but little is known about how loneliness causes depression. Are daily experiences of loneliness associated with daily experiences of depression? What factors, if any, might protect against feelings of depression subsequent to feelings of loneliness?

1.1. In search of an explanation

How one responds to momentary feelings of loneliness may predict whether they experience subsequent feelings of depression. Cacioppo et al. (2006) and Cacioppo and Cacioppo (2018) suggest that the experience of loneliness motivates individuals to seek out and establish social connections (i.e., the reaffiliation motive; Qualter et al., 2015). They also suggest, however, that loneliness may motivate social withdrawal and increased vigilance toward social threat. These seemingly antagonistic motivations may help explain the association between loneliness and depression. If momentary feelings of loneliness prompt people to socially withdraw and perceive others as exclusionary and perhaps even dangerous, this could increase risk for depression. On the other hand, if momentary feelings of loneliness motivate people to reconnect with others after periods of isolation, it would have the effect of protecting against depression (Kuczynski et al., 2022). It is thus possible that the nature of the association between loneliness and depression depends, in part, on whether an individual engages in social withdrawal versus social reaffiliation. In other words, when individuals engage in sufficient quantity of social interactions, or establish sufficiently meaningful interactions, they may avoid subsequent increases in depression compared to moments when they engage in the opposite response. Because loneliness is theorized to operate at the level of momentary experiences, it is important to understand whether momentary responses may differentiate moments when people experience negative versus positive/neutral outcomes.

The Interpersonal Process Model of Intimacy (Reis and Shaver, 1988) delineates characteristics of social interactions that may regulate the experience of loneliness and protect against subsequent increases in depression insofar as they lead to the development of close relationships (i.e., social reaffiliation). According to this model, interpersonal closeness is generated by a dyadic momentary process wherein individuals engage in an exchange of vulnerable, self-revealing self-disclosure and, in response, receive validation, understanding, and care (i.e., responsiveness). Kanter et al. (2020) have since expanded upon this model, additionally highlighting the role of non-verbal expression of emotion.

There are many possible reasons why interactions characterized by a reciprocal exchange of emotional expression and responsiveness may regulate the experience of loneliness. It is possible that increased interpersonal closeness resulting from this process may itself protect against depression (Kuczynski et al., 2022). It is also possible that such an exchange creates opportunities for others to regulate the lonely individual's emotional experience. For example, interaction partners may address unhelpful cognitions, generate hope, provide distraction, or engage in problem-solving that alleviates the experience of (Zaki and Williams, 2013). Others' expression of emotion may similarly serve to increase connection and downregulate feelings of isolation (Laurenceau et al., 1998), especially if that disclosure prompts additional ways of processing one's own emotional experiences (Marroquín, 2011).

Although loneliness is believed to be caused by momentary processes and serve momentary functions, most research in this area has assessed loneliness and depression in cross-sectional snapshots and longitudinal studies with measurement intervals that often span greater than one year (cf. Fried et al., 2022; Hawkley et al., 2010). In consequence, little is known about how the day-to-day experience of loneliness relates to momentary experiences of depression. Studying the momentary, within-person association between loneliness and depression is critical for integrating theoretical accounts of loneliness with the health outcomes literature, identifying possible intervention targets, and testing whether time-varying contextual factors (e.g., ongoing social interactions) moderate this association. Doing so may also shed light on whether time-varying characteristics of loneliness not possible to ascertain using retrospective report (e.g., autocorrelation, momentary variation) are related to its effect on depression. Assessing loneliness in the moment versus retrospectively also circumvents many of the biases exhibited in retrospective self-report, especially for depressed individuals (Ben-Zeev et al., 2009).

1.2. The current study

In this study, we aimed to (a) characterize the momentary association between feelings of loneliness and depressed mood and (b) identify the extent to which engagement in frequent and high-quality social interactions moderates this association. In a random-interval ecological momentary assessment study, we hypothesized that momentary (i.e., state) loneliness and depressed mood would co-occur, and that this contemporaneous association would be stronger for individuals who were lonelier on average and for individuals who were alone at the time of assessment. We also hypothesized that state loneliness would be associated with increased depressed mood at the next time point, and that this association would be stronger for individuals who were lonelier on average and weaker when an individual was more satisfied with their interactions since reporting feeling lonely, perceived their interactions as characterized by greater responsiveness (i.e., communicating understanding, validation, and care) and greater vulnerable self- and other-disclosure, and engaged in more frequent social interaction since feeling lonely. We focus specifically on the experience of depressed mood following experiences of loneliness (versus the opposite – loneliness following experiences of depression) given that our hypotheses pertain to the possible protective effects of loneliness sequelae (i.e., frequent, high-quality social interaction). Different processes likely underlie the association between depression and subsequent loneliness.

We also explored the prospective association between loneliness and depression at varying time lags (~5h, ~7.5h, and ~10h after experiencing loneliness), whether loneliness inertia (i.e., autocorrelation; Kuppens et al., 2010) and variability (i.e., mean squared successive difference; Jahng et al., 2008) were associated with depression, and given gender differences in depression and interpersonal functioning (Gadassi et al., 2011; Piccinelli and Wilkinson, 2000), whether gender moderated this association.

2. Method

We preregistered this study at https://osf.io/h87fw and https://osf.io/7vb5n. Data, power simulation and analysis code, and materials are publicly available at https://osf.io/7rkfm.

2.1. Participants

Participants were 103 adults ($M_{age} = 31.94$, range = 18–64) living in the United States with elevated depression symptoms recruited via advertisements on Facebook and Instagram. One participant did not complete any ecological momentary assessment surveys and was thus excluded from analysis. We recruited a balanced sample across race/ethnicity within the following five groups: Asian/Pacific Islander ($n = 20$), Black/African American ($n = 19$), Hispanic/Latino ($n = 20$), White/European American ($n = 20$), and multiracial/other ($n = 23$). Most participants were women ($n = 83$), in a romantic partnership ($n = 52$), lived with others ($n = 77$), and reported a diagnosis of one or more psychiatric conditions ($n = 58$). See Table 1 for detailed participant characteristics.

2.2. Procedure

Prospective participants were directed from the study's website to an

Table 1
Sample sociodemographic characteristics.

Characteristic	n	%
Gender		
Cisgender woman	83	82.18
Cisgender man	14	13.86
Transgender/non-conforming	4	3.96
Age		
18–24	32	32.37
25–34	37	36.27
35–44	17	16.667
45–54	11	10.78
54–64	5	4.90
Race		
Asian or Pacific Islander	20	19.61
Black or African American	19	18.63
Hispanic or Latino	20	19.61
White or European American	20	22.55
Not listed	23	19.61
Relationship status		
Married	18	17.65
In a relationship	34	33.33
Single	40	39.22
Divorced/annulled	5	4.90
Separated	2	1.96
Widowed	3	2.94
Sexual identity		
Straight	72	70.59
Gay/lesbian	6	5.88
Bisexual	17	16.67
Not listed	7	6.86
Living arrangement		
With others	77	75.49
Alone	25	24.51
Birth country		
United States	84	82.35
Not United States	18	17.65
Mental health treatment		
Yes, current/past treatment	74	72.55
No, current/past treatment	28	27.45
Psychiatric diagnoses		
Major depressive disorder	30	29.41
Persistent depressive disorder	6	5.88
Social anxiety disorder	10	9.80
Post-traumatic stress disorder	16	15.69
Generalized anxiety disorder	34	33.33
Comorbid diagnoses	34	33.33

online screening survey hosted on Qualtrics to determine eligibility. Eligible participants were current residents of the United States, 18–64 years old, owned a smartphone, reported average engagement in at least 1 social interactions per day, and scored ≥10 on the Patient Health Questionnaire – 9 (PHQ-9; including 1+ on items 1 [depressed mood] or 2 [anhedonia]; Kroenke et al., 2001). Participants were excluded if they were unwilling to provide identification, provided a VoIP (voice over internet protocol) phone number, or reported a geographic location inconsistent with their geotagged location (based on IP address).

Eligible participants met with a member of the study team for their baseline study visit using Zoom video-conferencing software. Participants completed self-report measures hosted through Qualtrics and were subsequently onboarded to the ecological momentary assessment phase. During this onboarding, participants created an account and enrolled in our study using Inclivio (https://inclivio.com) and were oriented to the assessment protocol and survey items by a member of the study team. The ecological momentary assessment period began the following day.

Ecological momentary assessment surveys were sent to participants 5x/day for 14 days for a total of 70 assessments. Surveys were sent randomly within five 150-min (2.5 h) blocks, with consecutive surveys separated by at least 120 min. Participants had 90 min to complete each survey and were sent up to 4 reminders if they did not complete it within 15-min of receiving the notification. Surveys were sent to most participants within the following blocks of time: 0900–1130, 1130–1400, 1400–1630, 1630–1900, 1900–2130. These intervals were shifted up and down for a minority of participants to accommodate their wake/sleep schedules. All survey notifications were sent by text message (i.e., SMS) using Inclivio and hosted on Qualtrics.

Participants were compensated USD$25 for completing the baseline study visit, USD$1 for each completed ecological momentary assessment survey, and an additional USD$30 if they completed 90 % or more (63+) of the ecological momentary assessment surveys.

2.3. Measures

The full set of items for each construct are presented in Table 2.

2.3.1. State depressed mood

State depressed mood was measured using 11 items adapted from the PHQ-9 (Kroenke et al., 2001) that capture depressed mood (8 items) and anhedonia (3 items). The items "I feel depressed" and "I have little interest in doing things right now" were presented at each assessment with a random subset of 4 of 7 remaining depressed mood items and 1 of 2 remaining anhedonia items. Participants rated each item on a visual analog scale ranging from 0 (*Not at all*) to 100 (*Very much so*). A total score was computed by taking the mean across all 11 items. These items demonstrated strong reliability at the between-person (ω_b = .96) and within-person (ω_w = .89) levels (ICC = .54).

2.3.2. State loneliness

State loneliness was measured using 12 items adapted from various sources, including items from the UCLA Loneliness Scale (version 3; Russell, 1996), items derived based on theoretical conceptualizations of loneliness (loneliness as 'perceived social isolation'), an item previously used to measure thwarted belongingness (Van Orden et al., 2012), and a face-valid single-item indicator most often used in ecological momentary assessment studies of loneliness ("I feel lonely"). "I feel lonely" was asked at each assessment with a random subset of 5 of the remaining 11 items. Participants rated each item on a visual analog scale ranging from 0 (*Not at all*) to 100 (*Very much so*). A total score was computed by taking the mean across all 12 items after reverse scoring the 5 positively valenced items. These items demonstrated strong reliability at the between-person (ω_b = .95) and within-person (ω_w = .87) levels (ICC = .56).

2.3.3. State social interaction quantity

Social interaction quantity was measured using the single item "how many social interactions have you had since the last prompt?" Consistent with previous research (e.g., Nauta et al., 2020), participants were instructed to include interactions 5+ minutes in duration with an individual who was 7+ years old. Participants were instructed to include all interaction modalities (i.e., in-person or virtual). Response options ranged from '0' to '25 or more' interactions (ICC = .35).

2.3.4. Social interaction characteristics

Participants who engaged in at least one social interaction since the previous survey responded to the following questions about those interactions.

Participants indicated how satisfied they were with their interactions (**social interaction satisfaction**; "how satisfied did you feel with these interactions?"; ICC = .48) using a slider ranging from 0 (*Not at all satisfied*) to 100 (*Very satisfied*).

Item measuring interaction characteristics pertaining to Reis and Shaver's (1988) Interpersonal Process Model were adapted from existing EMA literature (e.g., Laurenceau et al., 1998), Reis and Shaver's (1988) theoretical delineation of these variables, and Kanter et al.'s (2020) review of the literature. **State vulnerable self-disclosure** (ICC = .49) was measured using a slider scale ranging from 0 (*Not at all*) to 100 (*Very much so*): "I let others see how I was feeling non-verbally," "I expressed closeness with others," "I shared how I felt with others," and "I shared

Table 2
Items for each construct in our planned-missingness anchor-test design.

Loneliness (6 items)
1. *I feel lonely*
2. I feel "in tune" with those around me
3. I feel part of a group of friends
4. I feel included by others
5. I feel close to people
6. I feel that there are people I can talk to
7. I feel that I lack companionship
8. I feel alone
9. I do not feel close to others
10. I feel like I don't belong
11. I feel isolated from others
12. I feel left out

State depressed mood (7 items)
[Depressed mood: n = 5]

1. *I feel depressed*
2. I feel hopeless
3. I feel down
4. I feel worthless
5. I feel discouraged
6. I feel sad
7. I feel like a failure
8. I feel disappointed in myself

[Anhedonia: n = 2]

9. *I have little interest in doing things right now*
10. I have found little pleasure in the things I did since the last prompt
11. I am enjoying myself right now

State social interaction quantity (1 item)
How many social interactions have you had since the last prompt?

State social interaction satisfaction (1 item)
How satisfied did you feel with these interactions?

State vulnerable self-disclosure (3 items)
1. *I let others see how I was feeling non-verbally*
2. *I expressed closeness with others*
3. I shared how I felt with others
4. I shared personal information with others

State vulnerable other-disclosure (3 items)
1. *Others let me see how they were feeling non-verbally*
2. *Others expressed closeness with me*
3. Others shared how they felt with me
4. Others shared personal information with me

State perceived responsiveness (2 items)
[n = 1]

1. I felt understood by others
2. I felt cared about by others
3. I felt validated by others

[n = 1]

1. I felt that others were not interested in me
2. I felt criticized by others
3. I felt rejected by others

State solitude (1 item)
Are you alone or with others right now?

Note. Anchor items (items asked at all assessments) are italicized. Constructs measured by a single item were presented at all assessments. Item numbers in parentheses indicate the number of total items presented at each time point.

personal information with others." **State vulnerable other-disclosure** (ICC = .48) was measured using 4 similar items on the same scale: "Others let me see how they were feeling non-verbally," "Others expressed closeness with me," "Others shared how they felt with me," and "Others shared personal information with me." For each construct, three items (the first two plus a random selection of the latter two) were presented at each assessment. Total scores were computed by taking the mean across all 4 items. These items demonstrated strong between-person (self-disclosure: ω_b = .93; other-disclosure: ω_b = .93) and within-person (self-disclosure: ω_w = .79; other-disclosure: ω_w = .79)

reliability.

State perceived responsiveness was measured using a slider scale ranging from 0 (*Not at all*) to 100 (*Very much so*): "I felt understood by others," "I felt cared about by others," "I felt validated by others," "I felt that others were not interested in me," "I felt criticized by others," and "I felt rejected by others." Four of these items were randomly presented at each assessment. A total score was computed by taking the mean across all 6 items after reverse scoring the negatively valenced items. These items demonstrated strong between-person (ω_b = .88) and within-person (ω_w = .75) reliability (ICC = .49).

State solitude (i.e., aloneness) was measured using the single item "Are you alone or with others right now?" Participants were instructed to select "with others" if they were engaged in virtual social interaction at the time of the survey (e.g., phone call, video chat) and "alone" if they were at their residence with others but in a separate room (ICC = .32).

2.3.5. Trait loneliness

Trait loneliness was measured at baseline using the 20-item UCLA Loneliness Scale (version 3; Russell, 1996). A total score was computed by taking the sum across all 20 items after reverse scoring the positively valenced items. Reliability was strong in the current sample (ω = .91).

2.4. Analytic approach

2.4.1. Missing data

Excluding data that were missing by design and those due to completely missed assessments (8%), missing data were rare (around 1% for each variable). We used fully conditional specification implemented in Blimp (version 3; Enders et al., 2020) to impute missing data at the item-level for all state variables, which was possible given that most data were known to be missing completely at random due to our planning missingness design. Person-level variables (e.g., age, relationship status) were included in our imputation model to improve prediction accuracy. Maximum potential scale reduction factors ($\widehat{R}$) near 1.00 and density plots of the imputed (n = 20 datasets) versus fully-observed values indicated that the imputation process converged on stable estimates.

2.4.2. Mixed effects models

Bayesian mixed effects location scale models (Hedeker et al., 2008) were used to address our primary hypotheses and exploratory aims. Mixed effects models account for non-independence (i.e., clustering, nesting) of observations by modeling person-level differences in parameter estimates (i.e., intercepts, slopes) as random variables. In contrast with traditional 'location-only' mixed effects models, location scale mixed effects models model variation (i.e., 'scale') in addition to mean (i.e., location) outcomes. Thus, by using location-scale models, we were able to model the association between loneliness and variability in depressed mood and relax the assumption of homoscedastic error variance across time and person.

We constructed eight separate location scale models to address our primary hypotheses. State predictor variables were centered around each participant's mean, which enables estimation of within-person effects separate from between-person effects (Wang and Maxwell, 2015). Study day, ping number (i.e., survey number on a given day; 1–5), and a dummy for weekend versus weekday were included in each model to account for any time trends and seasonality. Random intercepts were estimated in the location and scale submodels, and random slopes of the contemporaneous and prospective effects of state loneliness were also included. A log-linear scale submodel was used to ensure that estimates of within-person variation remained positive. A first-order autoregressive structure was placed on the within-person residuals to account for autocorrelated error caused by the repeated measures nature of the data.

We chose to use weakly informative priors in line with recommendations by Gelman et al. (2017). With a sufficiently large sample, these priors function to regularize parameters while yielding minimal influence on the final estimates. We specified the following priors:

$$\beta_0 \sim N(50, 10)$$
$$\beta_{state\ loneliness\ (t)} \sim N(0, 0.50)$$
$$\beta_{state\ loneliness\ (t-1)} \sim N(0, 0.30)$$

We considered main effects ranging from 0 to 0.10 as "null", 0.10 to 0.25 as "meaningful", and > 0.25 as "large". Estimates of interaction effects were interpreted with respect to these values by identifying levels of the moderator at which the main effect is null, meaningful, or large.

All models were estimated using the brms package (version 2.17.0; Bürkner, 2021) for R (version 4.1.1; R Core Team, 2022). We assessed model convergence and fit by inspecting potential scale reduction factor ($\widehat{R}$) values, effective sample sizes, trace plots, and posterior predictive checks (see Dora et al., 2022). R code for all analyses can be found on this project's OSF page (https://osf.io/7rkfm).

To present our findings, we discuss the magnitude of each effect and how much individual-level variation we observed around this effect. We also discuss how accurately we estimated each effect by describing the shape of the posterior distribution (a probability distribution of effect sizes; see Van De Schoot et al., 2021 for a review). The area of the posterior distribution above a certain value represents the probability (given the prior beliefs and data) that the parameter is at or above that value.

3. Results

A total of 6568 surveys were completed by participants (surveys per participant: M = 64.39 [91.99% of total], Mdn = 68, SD = 11.63). Most participants (83.33%) completed 90% or more of the surveys, and nearly everyone (96.08 %) completed at least half of all surveys.

3.1. Scale submodel simplification

Estimates of the scale submodel parameters across all models provided little evidence of an effect of time, seasonality within day or by week/weekend, state and trait loneliness, and their interaction on variation in depressed mood (see Table 3 for scale submodel results). In other words, how much participants' depressed mood varied was relatively stable over the 14-day study period and was not associated with their experience of loneliness. Given this, to facilitate a clearer interpretation of the scale submodel intercept, we removed all covariates and estimated a random intercept-only scale submodel for each analysis (deviating from our preregistered data analytic plan). In this simplified scale submodel, the random intercept represents between-subjects variation in depressed mood variability. Results showed that, on average, people varied 10.48 points around their average depressed mood score (95% CI = 9.85 to 11.15; Mean state depressed mood = 32.12; State depressed mood scores ranged from 0 to 100). Some participants had greater variation in depressed mood than other participants (68% of values ranged from 7.74 to 13.25; see Fig. 1).

Table 3
Scale submodel parameter estimates from H1a and H1c mixed effects location scale model.

Parameter	b	SE	95 % CI
$\widehat{\sigma}_0$	2.38	0.04	2.30 to 2.46
$\widehat{\sigma}_{study\ day}$	−0.01	0.003	−0.01 to −0.0002
$\widehat{\sigma}_{ping\ number}$	0.003	0.008	−0.01 to 0.02
$\widehat{\sigma}_{weekend}$	−0.03	0.03	−0.08 to 0.02
$\widehat{\sigma}_{state\ loneliness}$	0.01	0.001	0.004 to 0.01
$\widehat{\sigma}_{trait\ loneliness}$	0.01	0.003	0.003 to 0.02
$\widehat{\sigma}_{state \times trait\ loneliness}$	−0.0003	0.0001	−0.001 to 0.00002

Note. The scale submodel was modeled as log-linear to ensure positive parameter estimates. Values presented herein are on the log-linear scale.

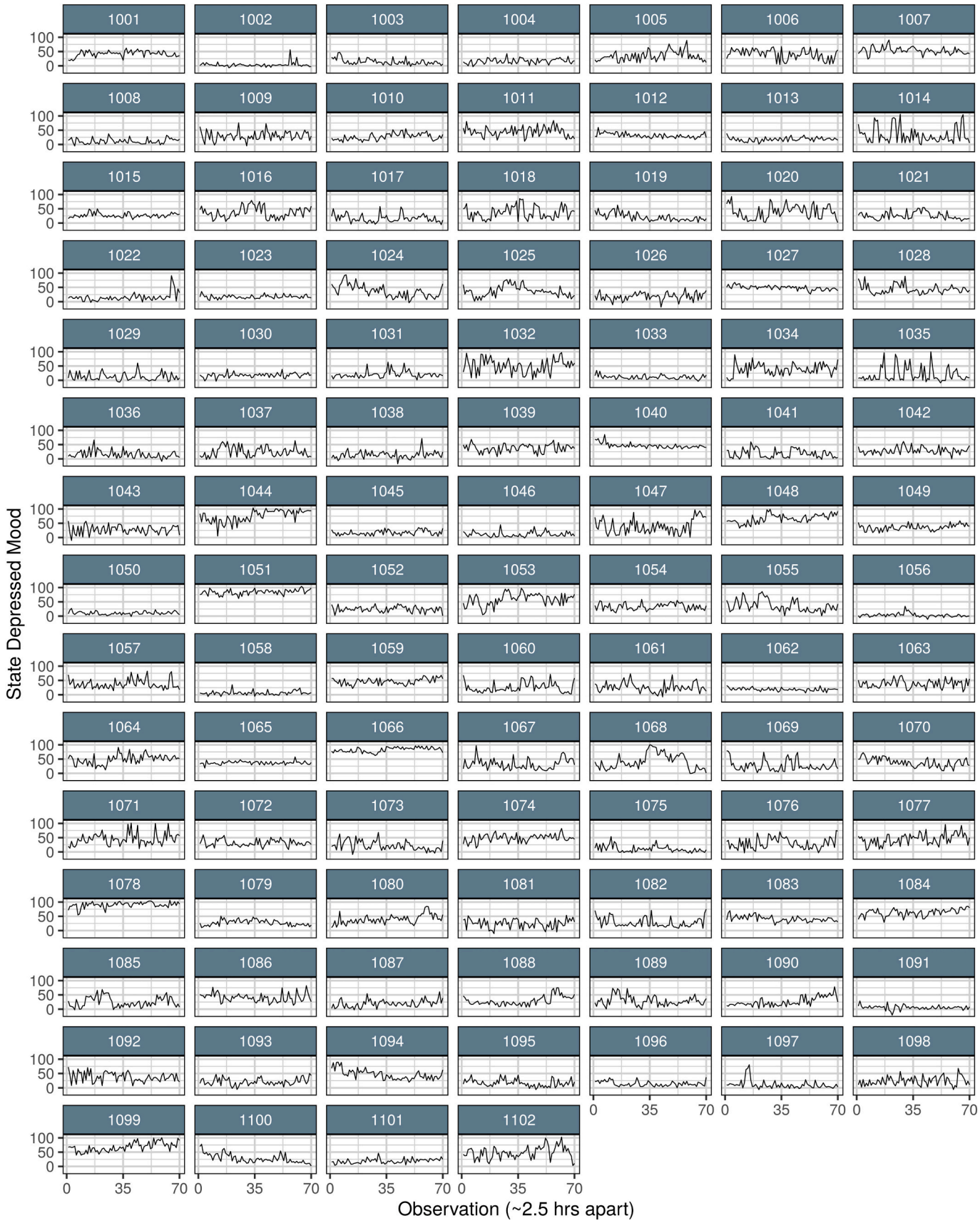

Fig. 1. Individual time series plots of model predicted state depressed mood scores.

3.2. Association between momentary loneliness and depressed mood

Posterior predictive checks, potential scale reduction factor ($\widehat{R}$) values, effective sample size metrics, and trace/density plots indicated that our model converged and fit the data well.

Table 4 presents a summary of our main findings. There was a positive, contemporaneous association between state loneliness and depressed mood such that, on average, depressed mood increased 5.2 units (of 100 total; 5.2%) for every 10 unit increase above one's average level of loneliness (b = 0.52, SE = 0.02, 95% CI = 0.47 to 0.56). Regarding the size of the effect, nearly the entire area of the posterior distribution lay above 0.25 (our pre-registered indicator of a "large" effect). There was substantial person-level variation around this effect, with the middle 68% lying between 0.34 and 0.68 (see Fig. 2).

Higher levels of state loneliness were also associated with greater levels of depressed mood at the next time point such that, on average, depressed mood increased 1.1 units (1.1%) for every 10 units increase above one's average level of loneliness (b = 0.11, SE = 0.01, 95% CI = 0.09 to 0.14). Most of the posterior distribution (85%) lay above 0.10, which provides relatively strong evidence in favor of this effect. We found meaningful person-level variation in this effect, with the middle 68% lying between 0.07 and 0.16 (Fig. 3).

A small effect of state loneliness at t-2 was observed controlling for its lag-1 and contemporaneous such that depressed mood increased 0.5 units for every 10 unit increase above one's average level of loneliness effects (b = 0.05, SE = 0.01, 95% CI = 0.02 to 0.07). Notably, the 95% credible interval was large, and spans effects we deemed, a priori, insignificant in size. We did not observe strong evidence for an effect of state loneliness at t-3 (b = 0.03, SE = 0.02, 95 % CI = −0.01 to 0.07) nor t-4 (b = −0.004, SE = 0.03, 95 % CI = −0.06 to 0.05).

Contrary to our hypothesis, trait loneliness did not moderate the contemporaneous nor prospective association between loneliness and depressed mood, nor did social interaction satisfaction, state perceived responsiveness, self-disclosure other-disclosure, social interaction quantity, and state solitude. Gender also did not moderate the contemporaneous (b = 0.01, SE = 0.05, 95% CI = −0.08 to 0.11) nor prospective (b = 0.03, SE = 0.04, 95 % CI = −0.05 to 0.10) association between state loneliness and depressed mood.

We did not find evidence of an effect of loneliness variation in the current study. Neither loneliness autocorrelation (b = −8.57, SE = 9.05, 95% CI = −26.44 to 9.00) nor mean squared successive difference (b = −0.01, SE = 0.01, 95% CI = −0.03 to 0.01) was associated with depressed mood.

Table 4
Results from Mixed-effects Location Scale Models.

Parameter	b	SE	95 % CI
Intercepts			
Location submodel (b_0)	32.75	1.58	29.67 to 35.89
Scale submodel ($\hat{\sigma}_0$)	2.35	0.03	2.29 to 2.41
Within-person effects			
State loneliness (t)	0.52	0.02	0.47 to 0.56
State loneliness ($t-1$)	0.11	0.01	0.09 to 0.14
Social interaction satisfaction (t)	−0.10	0.01	−0.13 to −0.08
Perceived responsiveness (t)	−0.13	0.02	−0.17 to −0.09
Self-disclosure (t)	0.003	0.01	−0.02 to 0.02
Other-disclosure (t)	−0.001	0.01	−0.02 to 0.02
Social interaction quantity (t)	−0.08	0.09	−0.24 to 0.10
Solitude (t)	1.17	0.37	0.47 to 1.91
Between-person effects			
Trait loneliness	0.80	0.16	0.48 to 1.12
Cross-level interactions			
Trait loneliness × state loneliness (t)	0.003	0.002	−0.001 to 0.007
Trait loneliness × state loneliness ($t-1$)	0.0004	0.001	−0.003 to 0.003
State loneliness ($t-1$) × social interaction satisfaction	−0.001	0.001	−0.002 to 0.001
State loneliness ($t-1$) × perceived responsiveness	−0.001	0.001	−0.003 to 0.0001
State loneliness ($t-1$) × self-disclosure	−0.001	0.001	−0.002 to 0.001
State loneliness ($t-1$) × other-disclosure	−0.001	0.001	−0.002 to 0.001
State loneliness ($t-1$) × social interaction quantity	−0.004	0.006	−0.02 to 0.01
State loneliness ($t-1$) × solitude	0.02	0.02	−0.03 to 0.07
Variance components			
SD: b_0	15.56	1.15	13.51 to 17.99
SD: $b_{0\varepsilon}$	0.30	0.02	0.25 to 0.35
SD: State loneliness (t)	0.20	0.02	0.16 to 0.24
SD: State loneliness ($t-1$)	0.08	0.02	0.03 to 0.12
Cor: b_0, $b_{0\varepsilon}$	0.16	0.11	−0.05 to 0.37
Cor: State loneliness (t), b_0	0.08	0.12	−0.15 to 0.31
Cor: State loneliness (t), $b_{0\varepsilon}$	0.67	0.09	0.48 to 0.82
Cor: State loneliness ($t-1$), b_0	0.15	0.20	−0.25 to 0.52
Cor: State loneliness ($t-1$), $b_{0\varepsilon}$	0.27	0.22	−0.16 to 0.69

4. Discussion

Results from this study demonstrate that momentary feelings of loneliness were associated with depressed mood not only at the same time point, but also ~2.5h and ~ 5h later. As expected, the prospective association became weaker over time. Identifying predictors of momentary depressed mood is a worthwhile goal given that momentary feelings are associated with functional impairment (Cuijpers and Smit, 2004; Lewinsohn et al., 2000) and may be involved in the pathogenesis of clinical depression (Nelson et al., 2017; Wichers, 2014). Findings from this study demonstrate that loneliness is one such predictor, and that targeting momentary feelings of loneliness could be an important depression intervention target.

Although these findings are unsurprising given clinical intuition and past observational longitudinal research, they are perplexing considering Cacioppo et al. (2006) and Cacioppo and Cacioppo's (2018) claim that loneliness motivates social interaction. Social interaction is generally protective against depressed mood (e.g., Kuczynski et al., 2022). Therefore, if feelings of loneliness motivate individuals to seek out social interaction, as their theory suggests, we would expect to see a negative rather than positive association with depression. Cacioppo et al. (2006) and Cacioppo and Cacioppo' (2018) theory reconciles this discrepancy by suggesting that loneliness may also promote a social stress response involving social withdrawal and reappraisal of one's relationships. Thus, it is possible that people feel depressed subsequent to feelings of loneliness because, upon feeling lonely, they experience changes in social cognition (e.g., hypervigilance to social threat; Hawkley and Cacioppo, 2010) and engage in social withdrawal, both of which are associated with increased depressive symptoms.

We hypothesized that the association between momentary loneliness and depression would be weaker when individuals engaged in more frequent and satisfying social interactions, and social interactions characterized by self-disclosure, other-disclosure, and responsiveness. Findings from this study did not support these hypotheses. It is possible that changes in social cognition resulting from momentary feelings of loneliness affected individuals' experience of their interactions, preventing them from getting the full antidepressant benefits of frequent and high-quality interactions. When Arpin and Mohr (2019) experimentally manipulated loneliness in a controlled laboratory setting, for example, they found that those in the high-loneliness condition attributed less responsiveness to their interaction partner compared to those in the low-loneliness condition. Individuals who are chronically lonely also demonstrate differences in social cognition that may affect their experience of social interactions, such as a tendency to attribute inclusive interactions to external factors and exclusive interactions to internal and stable factors (Vanhalst et al., 2015). It is thus possible that what people need most when they are lonely – interactions characterized by mutual understanding, validation, care, and closeness – are perceptually

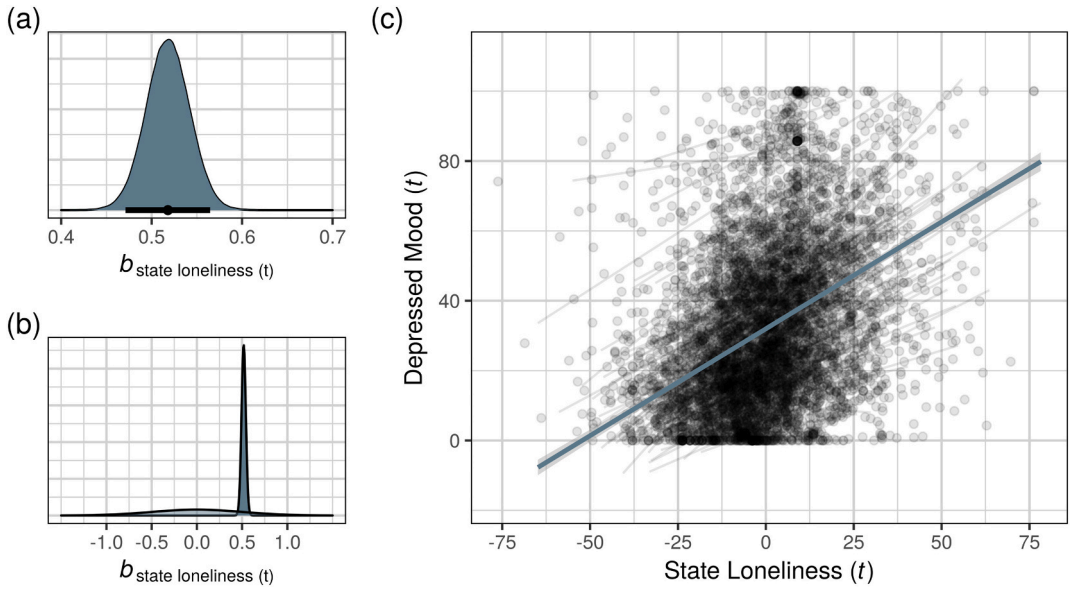

Fig. 2. Association between loneliness and depressed mood.
(a) Posterior distribution of the population-level association between state loneliness (*t*) and depressed mood (*t*) with values greater than our preregistered smallest effect size of interest (0.10) shaded; (b) posterior distribution superimposed on the prior distribution for the association between state loneliness (*t*) and depressed mood (*t*); (c) average (population-level) association between state loneliness (*t*) and depressed mood (*t*) with participant-level random slopes.

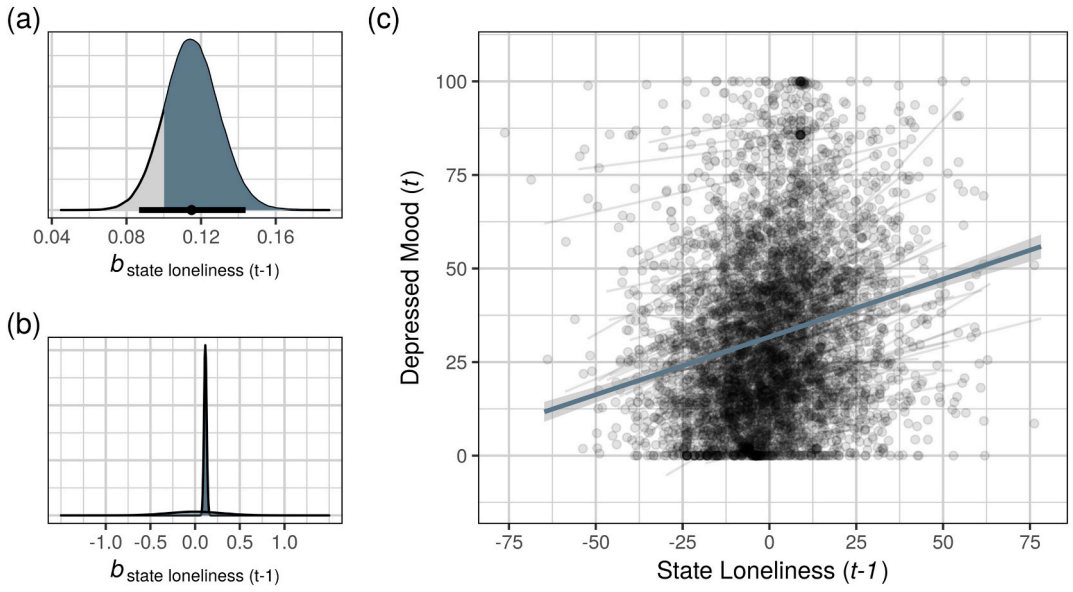

Fig. 3. Association between loneliness_{t-1} and depressed mood.
(a) Posterior distribution of the population-level association between state loneliness ($t-1$) and depressed mood (*t*) with values greater than our preregistered smallest effect size of interest (0.10) shaded; (b) posterior distribution superimposed on the prior distribution for the association between state loneliness ($t-1$) and depressed mood (*t*); (c) average (population-level) association between state loneliness ($t-1$) and depressed mood (*t*) with participant-level random slopes.

out of reach due to the experience of loneliness itself. It is also possible that other important interaction variables are influenced by loneliness (e.g., less selectivity in who one discloses to, more expressions of disclosures that are difficult for the recipient to respond to) such that, when people are feeling lonely, their interactions are characterized by fewer opportunities for connection or effective interpersonal emotion regulation.

Our findings may also be a unique function of our sample. Depressed individuals exhibit differences in reward processing, social cognition, and social behavior that may affect their interactions with others (Hames et al., 2013). Compared to non-depressed individuals, for example, depressed individuals consistently rate their interactions with others as less intimate and enjoyable (Nezlek et al., 1994, 2000). It is thus possible that social interactions moderate the association between momentary loneliness and depressed mood in non-depressed, but not already depressed, individuals. Future research should examine this possibility, as it would help to identify points of early intervention, elucidate possible contributing factors to the pathogenesis of clinical depression, and pinpoint interventions targets for already depressed samples.

We did not find evidence of more complex temporal dynamics in the current study. Individuals in our sample were no more depressed on days when they experienced more prolonged states of loneliness than on days when their loneliness was more fleeting, nor were they more

depressed on days when they experienced greater variability in loneliness compared to days characterized by less variability. These findings diverge from research discussed earlier showing depressed individuals tend to get stuck, and vary more, in negative affect compared to non-depressed individuals (Koval et al., 2012). It is possible that these null findings are specific to the assessment of loneliness rather than negative affect more generally. Although solitude inertia (the degree to which an individual becomes stuck in a state of social isolation) is associated with increased risk for depression (Elmer et al., 2020), this study is the first to our knowledge to look specifically at the effect of loneliness inertia.

4.1. Strengths, limitations, and future directions

Our study comes with many strengths. We recruited a racially and geographically diverse sample of adults in the United States, which increases the generalizability of our findings to individuals across racial and ethnic cultural groups (Roberts and Mortenson, 2022). Our a priori, pre-registered data analytic plan and open data and materials promotes confidence in the replicability and reproducibility of our findings (Forstmeier et al., 2017; Gelman and Loken, 2013; Munafò et al., 2017). Our anchor-test planned missingness design enabled us to optimize survey completion rates while including multi-item measures of our constructs. Our intensive longitudinal design allowed us to examine the effects of momentary experiences of loneliness and social interactions on depressed mood in a naturalistic setting, thereby increasing external validity and, importantly, contributing to an emerging literature on the causal association between loneliness and depression (Sbarra et al., 2023).

This study also has several limitations. Although we took measures to recruit a racially and ethnically diverse sample, individuals living outside of the United States were excluded. As a result, our sample was relatively culturally homogenous and, as Henrich et al. (2010) argue, our findings may therefore not generalize to individuals from other backgrounds. Future studies should include a more culturally diverse sample to assess whether differences may exist in these findings (e.g., along the individualism-collectivism dimension; Barreto et al., 2021; Taniguchi and Kaufman, 2021).

Data for this study were collected during the SARS-CoV-2 pandemic, a time when opportunities for social interaction were limited (Buecker and Horstmann, 2021). Cacioppo et al. (2006) and Cacioppo and Cacioppo's (2018) theory of loneliness rests on the assumption that opportunities for social interaction abound and thus, with sufficient desire, actual engagement in social interaction can follow. Although this assumption may not hold outside of the pandemic context for other reasons (e.g., marginalized/systematically excluded individuals), it is possible that people in our sample did not have opportunities to engage in as frequent or high-quality interactions as they would have if not for the pandemic. Future work should attempt to replicate these findings outside of the pandemic context.

Lastly, we are unable to determine causality given our observational design. Although the temporal nature of our data lends credence to this idea, our findings may be confounded by unmeasured between-person (e.g., neuroticism; Buecker et al., 2020; Kotov et al., 2010) or within-person (e.g., changes in social cognition; Bourke et al., 2010; Lim et al., 2016) variables, reverse causation, or selection bias. Future research employing experimental or quasi-experimental methods is necessary to establish stronger conclusions with respect to causal associations.

5. Conclusion

Evidence of the public health significance of loneliness is growing. Lonely people are also more depressed (Erzen and Çikrikci, 2018), and experiences of loneliness are associated with increased depressive symptoms over time (Cacioppo et al., 2010). Despite recent evidence that this association is causal (Sbarra et al., 2023), it is unknown why loneliness leads to depression and whether momentary versus chronic feelings of loneliness are implicated. This study provides evidence that moment experiences of loneliness are associated with depressed mood concurrently as well as ~2.5h and ~ 5h later. Contrary to our hypotheses, engaging in frequent and high-quality social interactions did not buffer against depression subsequent to feelings of loneliness. It is possible that changes in reward processing and social cognition characteristic of loneliness and depression (Arpin and Mohr, 2019; Hames et al., 2013) prevented individuals from capitalizing on the positive benefits of social interactions. Future research should investigate this possibility, as it may shed light on possible intervention targets.

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CRediT authorship contribution statement

Adam M. Kuczynski: Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Marilyn L. Piccirillo:** Writing – review & editing, Formal analysis. **Jonas Dora:** Writing – review & editing, Methodology, Formal analysis. **Kevin S. Keuhn:** Writing – review & editing. **Max A. Halvorson:** Writing – review & editing, Formal analysis. **Kevin M. King:** Writing – review & editing, Methodology. **Jonathan W. Kanter:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

None.

Data availability

Data, power simulation and analysis code, and study materials are openly accessible at https://osf.io/7rkfm. Our preregistered hypotheses and analysis plan are accessible at https://osf.io/h87fw and https://osf.io/7vb5n.

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