People who need people: Trait loneliness influences positive affect as a function of interpersonal context

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Abstract:

Trait loneliness is associated with negative health consequences; understanding involved processes may elucidate its contributory role. Evolutionary and reaffiliative models associate loneliness with negative affect and dysregulated cortisol responding, while the social monitoring system model associates loneliness with heightened salience of social cues. We hypothesized that loneliness would be associated with greater negative affect and cortisol reactivity, comparing a negative-evaluative audience Trier Social Stress Test ("audience condition;" n = 55) versus a no-audience control condition (n = 69) in non-depressed young adults. Opposing hypotheses, multilevel growth curve models indicated that loneliness was not associated with negative affect or cortisol reactivity in the audience versus no-audience condition. Loneliness was, however, associated with greater positive affect reactivity in the audience versus no-audience condition. In particular, the positive affect subfacet "Interest" was heightened in the audience condition but blunted in the no-audience condition as a function of loneliness, echoing a social monitoring system model of loneliness.

Keywords: loneliness | social monitoring system | reaffiliation | positive affect | negative affect | Trier Social Stress Test | cortisol

Article:

1. Introduction

Humans have a basic need to experience reciprocal, satisfying social relationships (Baumeister & Leary, 1995) and deficits in this area have been shown to predict negative outcomes. Trait loneliness is the persisting, subjective perception of the discrepancy between one's actual and desired social relationships (Peplau & Perlman, 1982), and is associated with increased negative emotions (Cacioppo, Hawkley et al., 2006) such as worthlessness, depression and rejection

sensitivity (for review see, Heinrich & Gullone, 2006), as well as with negative health outcomes. Physical health correlates include weakened cardiovascular functioning (e.g., elevated total peripheral resistance and decreased cardiac output; Hawkley, Burleson, Berntson, & Cacioppo, 2003), dysregulated sleep (Cacioppo et al., 2002), and heightened stress reactivity (Hawkley et al., 2003). Negative mental health outcomes associated with loneliness include increased risk for anxiety and depression (Cacioppo, Hughes, Waite, Hawkley, & Thisted, 2006; Ernst & Cacioppo, 1999) and risk for suicide (Stravynski & Boyer, 2001). Several theories make predictions regarding the function of loneliness that can be tested under conditions of laboratory based social stress, which may suggest pathways by which loneliness is associated with negative outcomes. In the present study, we examine the relationship of trait loneliness to affective and neuroendocrine responses to an explicitly negative evaluative social challenge versus non-social control versions of the Trier Social Stress Test (TSST; Kirschbaum, Pirke, & Hellhammer, 1993) in young adults.

1.1. Theories of loneliness

Here we briefly describe three relevant theories of loneliness and their predictions for responding to social stress. First, an evolutionary perspective of loneliness suggests that in social species loneliness evolved as an adaptive mechanism and is posited to produce an "aversive state" (Cacioppo, Cacioppo, Boomsma, 2014, p. 1), which elicits "social pain" (p.1056), feeling unsafe, heightened threat sensitivity and negative social information bias (Cacioppo, Hawkley et al., 2006) to signal deteriorating bonds, which in the short-term facilitates survival by guiding reaffiliative behavior (Cacioppo et al., 2014, Cacioppo et al., 2015). Second, the reaffiliation theory extends this evolutionary perspective by emphasizing the motivation to reaffiliate (Qualter et al., 2015). In this model, cues of social disconnectedness activate adaptive cognitive processes (e.g., attention to social information both negative and positive), which trigger reconnecting behaviors. However, a maladaptive response to these cues can result in negative information bias, threat hypervigilance, continued withdrawal, and ongoing loneliness and negative affect (Qualter et al., 2015). Third, a social monitoring system perspective (Gardner, Pickett, Jefferis, & Knowles, 2005) focuses on the salience of the social context to loneliness. Similar to both the evolutionary and reaffiliation perspectives, this model proposes that lonely individuals are highly sensitive to social context, and possess enhanced processing and interpretation of socially salient information (Gardner, Pickett, & Brewer, 2000; Gardner et al., 2005; Pickett, Gardner, & Knowles, 2004).

These models share in common the view that the function of loneliness is to motivate individuals to reestablish social connections. Additionally, they emphasize that loneliness connotes sensitivity to social context, but they differ in what valence of social context is posited to be most salient. Whereas the evolutionary model highlights the contributory role of negative social information, the reaffiliation and social monitoring systems emphasize the adaptive role of attending to all social information, both positive and negative. One distinguishing factor between these two latter theories is that in the reaffiliation model an adaptive response leads to reconnection, whereas as unremitted loneliness, the focus of this paper, is associated with social threat hypervigilance and negativity bias not specified in the social monitoring system model. Collectively, these theories suggest that loneliness is associated with aversive feelings, which may make social interactions feel more threatening, particularly under negative evaluative social conditions.

1.2. Loneliness and affect

Dysregulated affect is implicated in several negative mental health outcomes associated with loneliness, including depression, and is thus of interest in understanding processes operating in loneliness. Both increased negative affect (mood states including hostility, fear, and sadness) and diminished positive affect (mood states including interest, joy, and activation; Egloff, Schmukle, Burns, Kohlmann, & Hock, 2003) are relevant to mental health outcomes (Pizzagalli, Jahn, & O'Shea, 2005), and have also been associated with loneliness (Ernst & Cacioppo, 1999; Heinrich & Gullone, 2006). Affective dysregulation in social settings such as a negative evaluative lab-based stress induction might be particularly relevant to loneliness, and the models of loneliness described above suggest predictions.

The aversive state of loneliness in the evolutionary model, contributes to threat-hypervigilance, and has been linked to depressed, negative mood, and increased fear of evaluation (Cacioppo & Hawkley, 2009; Cacioppo et al., 2014; Cacioppo, Hawkley et al., 2006; Cacioppo, Hughes et al., 2006) as well as dampened momentary positive affect in a social context (Roekel et al., 2014). According to the reaffiliative theory, loneliness in an adaptive mechanism activates reaffiliation; however, in a maladaptive mechanism reconnection behaviors are not triggered, instead negative mood states such as threat-bias, withdrawal, negative affect, and prolonged feelings of loneliness ensue (Qualter et al., 2015). Examined through a social monitoring system lens, lonely individuals find both positive and negative social information highly salient, which helps guide individuals to appropriate reinclusion behaviors (Gardner et al., 2000, Gardner et al., 2005). Heightened salience for negative social context would suggest an association between loneliness and negative affect; however, predictions are less clear regarding attunement to social cues and positive affect outcomes. One possibility is that greater social salience might be reflected in measures of positive affect, particularly its facets activation and interest, identified through dynamic cluster analysis (Egloff et al., 2003). Thus, the social monitoring theory of loneliness hints that loneliness will be associated with heightened salience of and attunement to the social environment and perhaps greater engagement in the presence of others compared to when alone, captured by increased positive affective reactivity following social situations. Collectively, however, the above-described loneliness models provide more theoretical support for a hypothesis that loneliness will be associated with increased negative affect in general, and indirectly provide support for increased negative affect reactivity under a socially stressful situation such as the present study's social evaluative challenge.

1.3. Loneliness and cortisol

The dysregulation of cortisol, one indicator of hypothalamic-pituitary-adrenal (HPA) axis functioning, is one hypothesized mechanism through which loneliness contributes to negative health consequences, potentially due to experiencing social situations as more threatening (Cacioppo et al., 2002). No studies examine loneliness and cortisol reactivity in the context of lab-based social threat, but in naturalistic settings, loneliness is associated with flattened diurnal cortisol rhythms (Doane & Adam, 2010), suggesting a pattern of chronic HPA-axis wear and tear. Additionally, prior day loneliness predicted heightened cortisol awakening responses the following day (Adam, Hawkley, Kudielka, & Cacioppo, 2006), a marker of anticipating challenges in the upcoming day (Wetherell, Lovell, & Smith, 2015). Further, during the transition to college, perceived coping ability moderated the loneliness-diurnal cortisol slope association: Loneliness

was associated with flatter diurnal patterns in those with low perceived coping ability, but steeper, putatively healthier diurnal slopes in those with higher perceived coping ability (Drake, Sladek, & Doane, 2016). Finally, lonely individuals exhibited increased systolic blood pressure reactivity in response to the TSST compared to non-lonely individuals (Ong, Rothstein, & Uchino, 2012). Although the loneliness theories described here do not make direct hypotheses about cortisol reactivity, they generally suggest that social interactions are more threat-provoking for lonely individuals. Given that threat-provoking social evaluation has been shown to be a unique predictor of cortisol reactivity to lab-based manipulations in a meta-analysis (Dickerson & Kemeny, 2004), this suggests a hypothesis that loneliness will be associated with greater cortisol reactivity to lab-based social stress.

1.4. The present study

The present study examined the relationship of trait loneliness with affective and cortisol reactivity to a negative-evaluative Trier Social Stress Test with an audience evaluating performance (hereafter the "audience condition") versus a no-audience control protocol (hereafter the "no-audience condition") in non-depressed young adults. Previous research has examined the relationship between loneliness and affect in positive versus negative company (Roekel, Ha, Scholte, Engels, & Verhagen, 2016) but not when individuals were alone. The current paradigm allows examination of whether lonely individuals respond differentially in the presence versus absence of others. Based on theory and the evidence reviewed above, we hypothesized that loneliness would be associated with greater reactivity (i.e., indicated by greater curvilinear change in growth curve models) in negative affect and cortisol in the audience versus no-audience condition. We made no a priori hypotheses regarding loneliness predicting positive affect reactivity because there was not clear theoretical support across multiple models, although one model, the social monitoring system model, provides a basis for such a prediction.

2. Method

2.1. Participants

Introduction to Psychology students were recruited from a midsized, private midwestern university through an introductory psychology class offering course credit. Eligibility was determined based on mass-screening responses. Eligible participants were those at least 18 years of age who denied using nicotine, hormonal birth control, psychotropic or corticosteroid medications, and who denied all of the following: chronic health conditions, colorblindness, learning disability diagnosis, and history of head trauma (due to administration of cognitive tasks; data not presented here). All participants provided informed consent.

A minimum sample size of 120 was targeted for genetic aims not described here; this was chosen to be comparable to similar studies conducted at the time (e.g., N = 118, Way & Taylor, 2010). Two audience condition participants withdrew at the TSST, and one no-audience condition session was interrupted by a fire alarm, leaving a final sample size comprised of 124 participants (45 females; 18–23 years, Mage = 18.70, SD = 0.89) who completed the study and provided written permission for use of their data despite the study's deception. The racial distribution of the participants was Caucasian (n = 93, 75%), Asian (n = 11, 8.87%), Black (n = 4, 3.23%), Hispanic (n = 2, 1.61%), and multiracial (n = 13, 10.48%); one participant did not provide racial/ethnic

information (n = 1, 0.81%). After inspecting data for outliers, we excluded one no-audience condition participant from the cortisol analyses due to cortisol values, which were more than four standard deviations away from the mean cortisol values, which could indicate undiagnosed or unreported medical conditions, or may be a result of blood contamination of this persona's saliva from an oral lesion. Participants were assigned to experimental conditions pseudo-randomly (n = 69, no-audience; n = 55, audience condition); that is, participants were blind to the pre-scheduled study condition upon signing up via an automated system.

2.2. Procedures

The University's Institutional Review Board approved all study procedures. Participants were first screened to determine eligibility based on current depression symptoms at a mass testing session. Following informed consent, participants completed a diagnostic interview to rule out current depression, followed by computerized questionnaires, including a measure of trait loneliness. Next, participants completed the audience or no-audience condition TSST protocols, followed by a manipulation check questionnaire. Cortisol and momentary positive and negative affect were measured at baseline immediately prior to the TSST, after the TSST (+20 min from baseline), after cognitive tasks not reported here (+45 min), and after debriefing and brief rest (+60 min).

2.3. Materials

2.3.1. Diagnostic inventory for depression (DID)

The DID (Zimmerman, Sheeran, & Young, 2004) is a 19-item measure assessing the number and severity of the nine major depressive episode (MDE) symptoms of DSM-IV on a scale from 0 (denying a symptom) to 4 (severe endorsement). Ratings of 2 or higher indicate the symptom's presence. Suicidal ideation items were not collected as following up regarding individuals' immediate safety at mass screening was not feasible. Individuals who endorsed or left blank at least four MDE symptoms from the remaining eight were ineligible to complete the full study. In addition, DID scores served as a dimensional measure of subclinical depression symptoms.

2.3.2. UCLA loneliness scale-III (LS-III)

The UCLA LS-III (Russell, 1996) measures trait loneliness (perceived social isolation) and is a 20-question measure of satisfaction with one's social relationships on a scale of 1/never to 4/always. Each participant's mean item score (1–4) was calculated after reverse scoring positively framed items (α=0.925); higher scores indicate greater loneliness (Russell, 1996).

2.3.3. Positive and negative affect schedule (PANAS)

The PANAS is a self-report tool assessing affect with 10 single-word items each for positive and negative affect, using a scale ranging from 1/none-low to 5/extremely (Watson, Clark, & Tellegen, 1988). Participants were asked to report their mood "at this moment." Positive affect is often treated as a single measure; however, we calculated subfacet scores for post-hoc analyses as indicated by Egloff et al. (2003), who used cluster analysis to identify the subfacets Joy (excited,

proud, and enthusiastic), Interest (interested, determined, and strong), and Activation (attentive, inspired, and active).

2.3.4. Post-challenge manipulation check questionnaire

A 3-item questionnaire assessed, on a four-point scale (1–4), whether participants perceived they were being evaluated and the extent to which that evaluation was positive or negative.

2.3.5. Structured clinical interview, MDE section

Enrolled participants completed the MDE section of the Structured Clinical Interview for DSM-IV, Non-Patient edition (SCID; First, Spitzer, Gibbon, & Williams, 2001) to ensure that they had not developed a depressive episode since the screening (none had) and to assess past episodes. Trained undergraduate research assistants administered interviews; the principal investigator assigned final diagnoses in supervision. We excluded currently depressed individuals and we present results with and without covaried subclinical depression symptoms to avoid spurious findings for several reasons: (1) meta-analytic evidence suggests depressed individuals exhibit blunted cortisol reactivity and recovery in response to lab-based social threat (Burke, Davis, Otte, & Mohr, 2005); (2) clinically depressed mood predicts heightened negative affect and reduced positive affect (Watson, Clark, & Carey, 1988); and (3) loneliness and depression are correlated (Cacioppo, Hughes et al., 2006).

2.3.6. Cortisol sampling

Participants provided saliva samples for cortisol assessment via passive drool into sterile cryogenic vials. All saliva samples were collected in the afternoon (sessions started at 1:00PM and 3:30PM) to reduce time of day effects (Dickerson & Kemeny, 2004). Variations in cortisol intra-assays ranged from 4.0% to 6.7% and in inter-assays from 7.1% to 9.0%. Samples were stored at −20 °C then shipped to Trier, Germany on dry ice for time-resolved fluorescent-detection immunoassay in duplicate (DELFIA; Dressendörfer, Kirschbaum, Rohde, Stahl, & Strasburger, 1992). Following common practice, salivary cortisol levels were natural log-transformed for statistical analysis to address skew, but are depicted untransformed.

2.3.7. Trier Social Stress Test

The TSST is a widely used laboratory-induced psychosocial stressor (Kirschbaum et al., 1993). Participants completed either an explicitly negative-evaluative variant of the TSST in front of an audience of two confederate judges or a no-audience control protocol both derived from a reported protocol (Taylor et al., 2010). Using such a lab-based stressor enables testing a consistent “dose” (Dickerson & Kemeny, 2004) of a loneliness-relevant stressor (Cacioppo, Hawkley et al., 2006), and facilitates saliva collection for cortisol.

In each condition, participants were provided instructions and given five minutes each for speech preparation, speech presentation on a pre-assigned topic, and mental arithmetic (counting aloud backward from 2017 subtracting by 13s). Participants were told they would be videotaped; however, they were not actually video-recorded.

In the audience condition, participants presented on a self-evaluative speech topic (why their peers should elect them to a student leadership position) to a gender-balanced panel of two confederate judges trained to provide negative, terse, nonverbal feedback during the speech and arithmetic tasks. Additionally, confederates told participants they would analyze and evaluate the quality of their speech. The no-audience condition differed from the audience condition in three ways: Participants had no audience, they were told they would not be evaluated, and their speech topic was non-evaluative (talked about healthy lifestyle choices). The experimenter remained in the room outside of the participant's line of sight and spoke politely.

2.4. Statistical approach

Multilevel growth curve models examined the relationship of loneliness to changes in affect and cortisol levels (Singer & Willett, 2003). Following similar work (Zoccola, Dickerson, & Zaldivar, 2008), hypotheses focused on the expected rise and fall commonly observed in the TSST in each dependent variable, as modeled by a quadratic (curvilinear or inverted U-shaped) effect of time, which we refer to as reactivity (i.e., three-way interactions of Loneliness × Condition × Time2). We coded the audience condition as 1 and no-audience condition as 0 for the primary analyses. Results for linear effects of time captures simple increases or decreases in levels across the repeated measures (i.e., three-way interactions of Loneliness × Audience × Time). Although primary models contained no covariates, in follow-up analyses we included subclinical depression symptom level from the DID (and its necessary interaction terms, e.g., DID × Audience × Time2) to rule out the possibility of spurious results due to a correlation between subclinical depression and loneliness. Loneliness was standardized to center variables and aid interpretation. Anticipated post-hoc analyses in the event of significant findings were to examine empirically-supported subfacets of negative or positive affect, then to examine the simple quadratic slopes indicating the effect of trait loneliness on outcome reactivity for each condition. We did this first by inspecting the Loneliness × Time2 term in the full primary models to indicate the simple quadratic slope effect of Loneliness on outcome reactivity in the no-audience condition. Second, we reverse coded condition (No-Audience = 1, Audience = 0), re-ran the model, and inspected the Loneliness × Time2 term to indicate the simple quadratic slope effect of trait loneliness on outcome reactivity in the audience condition.

3. Results

3.1. Preliminary results

The audience and no-audience conditions did not significantly differ on gender, minority status, or major depressive episode history (all $\chi2(1) < 1.926$; $ps \geq 0.165$). There were no significant group differences in baseline cortisol, positive affect, negative affect, screener testing DID total score, or loneliness (all $Fs(1,121\text{-}123) \leq 2.206$; all $ps \geq 0.140$; all $\eta p2 \leq 0.018$). Loneliness scores1 were similar to previously reported norms and ranged from 21 to 65 ($M = 36.7$, $SD = 8.7$); refer to Table 1 for descriptive statistics. The conditions functioned as expected in manipulation checks. The audience condition reported feeling more evaluated ($M = 2.35$, $SD = 0.751$) than their no-audience condition counterparts ($M = 1.26$, $S = 0.803$; $F(1,122) = 58.331$; $p < 0.001$; $\eta p2 = 0.325$), and characterized these evaluations as more negative (audience: $M = 2.09$, $S = 0.727$; no-audience: $M = 0.82$, $SD = 0.695$; $F(1,115) = 92.567$; $p < 0.001$; $\eta p2 = 0.448$) and less positive (audience:

M = 0.49, SD = 0.605; no audience: M = 1.25, SD = 0.767; $F(1,115) = 34.136$; $p < 0.001$; $\eta p2 = 0.230$). We examined interclass correlations (ICCs) in multilevel regression models to determine the amount of variance attributable to moments within people (level 1) rather than stable between-person differences (level 2); these were 0.70 for cortisol, 0.28 for negative affect, and 0.62 for positive affect, supporting the use of multilevel models.

Table 1. Descriptive Statistics for Loneliness, Positive Affect, Negative Affect and Cortisol.

	No Audience Condition		**Audience Condition**	
	M	***SD***	***M***	***SD***
Loneliness Scale mean	37.2059	9.36739	36.1321	7.83247
Positive Affect Time0	2.5441	0.69139	2.4722	0.63940
Positive Affect Time1	2.5824	0.87450	2.4327	0.88319
Positive Affect Time2	2.0606	0.81767	2.0764	0.67549
Positive Affect Time3	2.2258	0.77048	2.2727	0.73923
Negative Affect Time0	1.3485	0.43003	1.2578	0.28517
Negative Affect Time1	1.5029	0.57041	1.8873	0.63510
Negative Affect Time2	1.2167	0.36610	1.2218	0.26225
Negative Affect Time3	1.1121	0.27317	1.1473	0.19327
Cortisol Time0	4.4804	2.51358	4.3532	2.56590
Cortisol Time1	4.5599	3.09958	5.9564	3.04058
Cortisol Time2	3.6541	1.80136	7.1327	4.48748
Cortisol Time3	3.4437	1.66756	5.8004	2.96978

Note: Time 0 = baseline, Time 1 = immediately following the TSST, about +20 min from baseline, Time 2 = immediately following cognitive tasks not reported here, about +45 min from baseline, Time 3 = following debriefing and brief rest, about +60 min after baseline. Cortisol values are given untransformed in nmols/L.

3.2. Loneliness and audience condition predicting affective reactivity

3.2.1. Positive affect

Random intercept models best fit the data; random slope models did not converge. First, a simple main effect of loneliness (i.e., when other effects were partialed out, referring to the effect of loneliness within the no-audience condition) revealed that higher levels of loneliness were associated with lower baseline positive affect within the no-audience condition (see Table 2 for statistical model; Lonely: B = −0.215, SE(B) = 0.082, $t(356) = -2.62$, $p = 0.009$), although the audience condition did not differ in this regard (Lonely x Audience, B = 0.155, SE(B) = 0.137, $t(356) = 1.12$, $p = 0.262$). Although the origin of this is unclear, lower baseline positive affect among higher loneliness individuals ought to hamper the ability to observe that loneliness is associated with declines in positive affect from the baseline measure in the no-audience condition given their lower starting point. Second, consistent with prior lab-based stress research, the manipulation did not perturb positive affect at the mean of loneliness, either considering linear growth (Audience × Time: B = −0.040, SE(B) = 0.129, $t(356) = -0.31$, $p = 0.757$) or curvilinear reactivity (Audience × Time2: B = 0.027, SE(B) = 0.041, $t(356) = 0.65$, $p = 0.515$). However, loneliness was associated with both increased linear growth in positive affect in the audience versus no-audience condition (Loneliness × Audience × Time: B = 0.330, SE(B) = 0.134,

t(356) = 2.47, p = 0.014) and increased reactivity in positive affect in the audience versus no-audience condition (Loneliness × Audience × Time2: B = −0.112, SE(B) = 0.043, t(356) = −2.63, p = 0.009; Fig. 1a). To follow up, we added subclinical levels of depression symptoms from the DID as a covariate2 to ensure that results for the interaction of loneliness and condition with quadratic time did not arise spuriously due to these symptoms; results for the Loneliness × Audience × Time2 effect in this model remained significant, B = −0.157, SE(B) = 0.045, t(352) = −3.52, p < 0.001, Table S3 in supplemental materials).

Table 2. Multilevel Growth Curve Model Predicting Positive Affect: Fixed Effects Results, No Covariates.

	B	SE(b)	df	t	p-value
Intercept	2.615	0.089	119	29.52	<0.0001
Time	−0.223	0.086	356	−2.59	0.010
Time2	0.028	0.028	356	1.01	0.313
Audience	−0.099	0.133	356	−0.74	0.459
Lonely	−0.215	0.082	356	−2.62	0.009
Audience × Time	−0.040	0.129	356	−0.31	0.757
Audience × Time2	0.027	0.041	356	0.65	0.515
Lonely × Time	−0.112	0.080	356	−1.4	0.163
Lonely × Time2 *	0.030	0.026	356	1.16	0.247
Lonely × Audience	0.155	0.137	356	1.12	0.262
Lonely × Audience × Time	0.330	0.134	356	2.47	0.014
Lonely × Audience × Time2	−0.112	0.043	356	−2.63	0.009

To gauge what might be driving the significant three-way interaction effect on positive affect, we decomposed positive affect into its three previously described facets, Interest, Joy, and Activation (Egloff et al., 2003), and examined loneliness (Loneliness × Audience × Time2) predicting reactivity in each facet in an exploratory fashion. This interaction significantly and robustly predicted reactivity in Interest (B = −0.160, SE(B) = 0.045, t(356) = −3.56, p = <0.001), also significantly predicted reactivity in Joy (B = −0.099, SE(B) = 0.049, t(356) = −2.01, p = 0.045), but did not significantly predict reactivity in Activation (B = −0.086, SE(B) = 0.053, t(356) = −1.63, p = 0.104). Thus, effects on positive affect most clearly represent changes in Interest. Although we have focused on interpreting results without covariates, follow-up analyses with subclinical depression symptoms covaried indicated that reactivity in all subfacets of positive affect, was associated with loneliness in interaction with audience condition (Lonely × Audience × Time2, with p-values ranging from <0.0001 to 0.012; models available in supplemental materials, Tables S4–S6), consistent with the outcome of our primary model.

Next, we further decomposed this interaction for Interest and Joy by examining the effect of loneliness on Interest and Joy reactivity by examining the simple quadratic slopes, first in the subfacet models reported above (where Lonely × Time2 indicates the simple quadratic slope for the No-Audience condition), and then in identical models with condition reverse coded (where Lonely × Time2 indicates the simple quadratic slope for the Audience condition). For Interest, this revealed that loneliness was associated with significantly greater reactivity in the audience condition (B = −0.106, SE(B) = 0.036, t(356) = −2.96, p = 0.003) and blunted reactivity in the no-audience condition (B = 0.054, SE(B) = 0.027, t(356) = 1.99, p = 0.048), see Table S7 and the Graphical Abstract. Thus, although we had not hypothesized that loneliness would be associated with differential changes in positive affect as a function of social context, such a pattern emerged

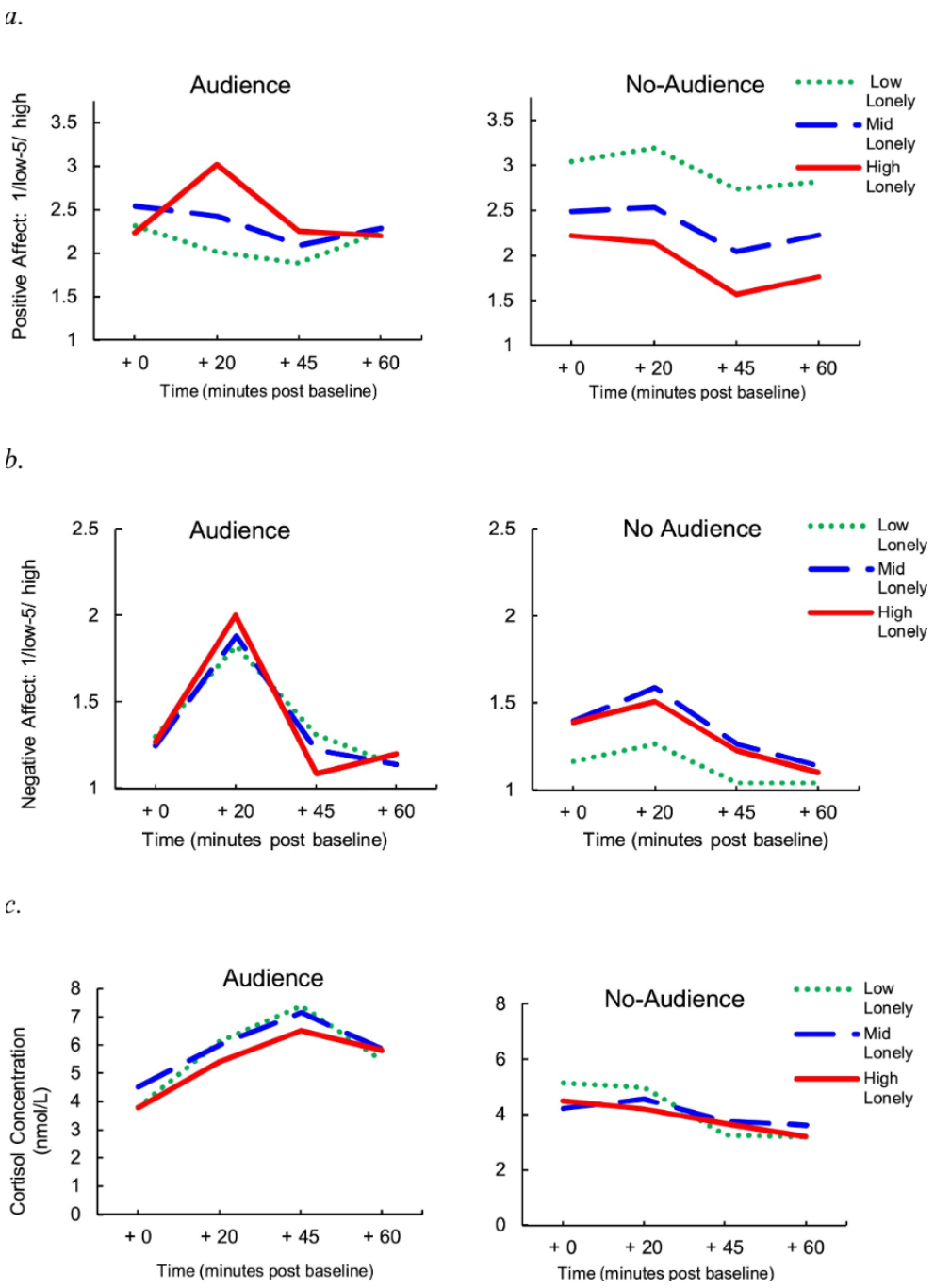

Fig. 1. a. Positive affect over time by loneliness and Trier Social Stress Test (TSST) condition. b. Negative affect over time by loneliness and TSST condition. c. Cortisol over time by loneliness and TSST condition.

Note. Regression analyses use dimensional loneliness; mean values from groups are used only to depict findings. UCLA Loneliness Scale-III values less than −1 standard deviation (SD) indicate lower trait loneliness (Low Lonely), −1 to +1 SD values indicate moderate trait loneliness (Mid Lonely), and values greater than +1 SD indicate higher trait loneliness (High Lonely).

across both conditions of the task in the Interest subfacet. Within the Joy subfacet, the results were non-significant for both the audience ($B = -0.069$, $SE(B) = 0.039$, $t(356) = -1.77$, $p = 0.078$) and no-audience conditions ($B = 0.029$, $SE(B) = 0.030$, $t(356) = 0.99$, $p = 0.323$, see Table S8), but the effects were in the same direction. These effects represent results without covariation of subclinical depression symptoms; Tables S4-S6 provide results with subclinical symptoms covaried. The pattern of significance was identical to that without covariates, except that the simple quadratic slope for Joy for the audience condition became significant ($p = 0.011$).

3.2.2. Negative affect

Random intercept models best fit the data; random slope models did not converge. The manipulation produced the expected effect on negative affect (at the mean of loneliness): The audience condition was associated with greater linear increases (Audience × Time: $B = 0.338$, $SE(B) = 0.096$, $t(356) = 3.53$, $p = 0.001$) and reactivity (Audience × Time2: $B = -0.113$, $SE(B) = 0.031$, $t(356) = -3.69$, $p < 0.001$) in negative affect over time. However, loneliness was not associated with greater negative affective reactivity in the audience condition (Loneliness × Audience × Time2: $B = 0.017$, $SE(B) = 0.032$, $t(356) = 0.54$, $p = 0.590$) or linear increases in negative affect in the audience condition (Loneliness × Audience × Time: $B = -0.038$, $SE(B) = 0.099$, $t(356) = -0.38$, $p = 0.705$; Fig. 1b). Thus, the data did not support our hypothesis that loneliness would be associated with greater negative affective reactivity in the audience condition. Given the non-significant finding with negative affect, we did not conduct post-hoc analyses for these results.

3.3. Loneliness predicting cortisol reactivity

A random slope model best fit the data. The manipulation produced the expected effect on cortisol at the mean of loneliness, indicating that individuals in the audience condition had both a greater linear increase in cortisol (Audience × Time: $B = 0.506$, $SE(B) = 0.064$, $t(235) = 7.92$, $p < 0.0001$) and greater curvilinear reactivity than did individuals in the no-audience condition (Audience × Time2: $B = -0.107$, $SE(B) = 0.019$, $t(235) = -5.74$, $p < 0.0001$). However, there was no evidence that loneliness significantly influenced cortisol reactivity in the audience condition (Loneliness × Audience × Time2: $B = 0.021$, $SE(B) = 0.019$, $t(235) = 1.08$, $p = 0.280$; Fig. 1c). We further examined the impact of gender3 on cortisol reactivity; gender terms were non-significant, and cortisol findings remained non-significant. Additionally, we included an interaction term with Sex x Loneliness x Stress x Time2, which also yielded non-significant findings.

4. Discussion

This study is the first to examine the influence of trait loneliness on affective and cortisol reactivity using a negative-evaluative audience condition versus a no-audience control. Contrary to hypotheses, loneliness was associated with significant reactivity in positive affect, but not with reactivity in negative affect or cortisol, during this lab-based social threat paradigm. Post-hoc analyses revealed that, of the three subfacets of positive affect—Interest, Joy, and Activation—the effects of loneliness were descriptively most pronounced for Interest. Moreover, greater loneliness was associated with greater reactivity in Interest within the audience condition but conversely

associated with blunted reactivity in Interest in the no-audience condition, heightening confidence in these unexpected findings.

4.1. Theoretical implications

These findings suggest that loneliness confers a heightened need for the presence of others to engage, reflected by increased Interest as a function of loneliness in our audience condition and a parallel blunting of Interest in our no-audience condition. In other words, loneliness captures greater social salience, not necessarily greater social threat sensitivity. Results, though contrary to hypotheses, most closely align with a social monitoring system theory of loneliness rather than evolutionary or reaffiliative theories; further, results are consistent with studies demonstrating that loneliness is associated with heightened salience of social information. For example, in one study socially rejected individuals reported heightened retention of social information compared to those in a social acceptance group (Gardner et al., 2000). Moreover, compared to individuals in the acceptance group, individuals in the rejected condition exhibited heightened recall for both positive and negative social events, suggesting that rather than valence (positive versus negative) the social component of information was critical for recall (Gardner et al., 2000). Further, in a daily diary study examining the impact of loneliness on sleep quality, greater experience of social connections on a given day was followed by better sleep that night, but only for those higher in loneliness (Sladek & Doane, 2015), highlighting the salience of social cues.

Our results augment the literature by demonstrating that loneliness is associated with increased interest in the presence of others. Importantly, these positive affect results do not explicitly conflict with the evolutionary and reaffiliative theories, as these posit that lonely individuals become hypersensitive to social cues during the reaffilitiave process (Cacioppo et al., 2014, Cacioppo et al., 2015; Qualter et al., 2015). Although these two theories do not directly predict an increase in positive affect, they do suggest that once an individual is motivated to reaffiliate, they become hyperattentive to social stimuli in particular.

4.2. Possible explanations for negative affect and cortisol null results

There are several potential reasons why results for negative affect and cortisol reactivity did not support hypotheses derived from evolutionary and reaffiliative theories of loneliness. First, null results may represent Type II error, although we believe this is unlikely given robust interactions of condition and time (at the mean of loneliness) on both negative affect and cortisol levels, and because the sample has produced significant cortisol results with genetic predictors in another study (Avery & Vrshek-Schallhorn, 2016). Second, it is possible that some prior observations of associations between loneliness and negative affect are due to a third variable, depression. Research has demonstrated that loneliness is associated with depression symptoms and the two share several characteristics; however, they are distinct constructs (Cacioppo, Hughes et al., 2006).

Prior studies that statistically controlled for depressive symptoms found a significant association between loneliness and increased negative affect (Steptoe, Leigh, & Kumari, 2011; Cacioppo, Hughes et al., 2006), but it is possible that a loneliness-depression association influenced results in a way for which simple covariation could not account. These could include a curvilinear relationship of depression symptoms to increasing negative affect or a covariate incompletely capturing the construct of depression. Our exclusion of currently depressed individuals, utilizing the DID and MDE section of the SCID and covarying levels of subclinical

depression symptoms, may have more thoroughly removed the influence of depression symptoms from both negative affect and cortisol results.

Finally, some loneliness theories suggest that loneliness can be adaptive in the short-term to signal lacking social bonds and produce an aversive state which motivates individuals to tend to their social relationships, but that the long-term impact of loneliness contributes to negative health outcomes (Qualter et al., 2015; Cacioppo, Hawkley et al., 2006). During periods of adjustment, such as the transition to college, loneliness has been shown to increase (Qualter et al., 2015; Sladek & Doane, 2015); although a strong influence of this transitional time on the absence of significant associations of loneliness with negative affect and cortisol reactivity is not parsimonious, we cannot rule it out.

4.3. Future directions

Several future directions are appropriate following our results that social context influences positive affective reactivity as a function of loneliness. First, because we did not predict this outcome, replication of this finding is particularly critical; this may be readily possible with existing lab-based stress datasets measuring both trait-like loneliness and positive affect reactivity. Second, the results suggest that contact with other people and resulting positive affect might be critical mediators of loneliness on negative health outcomes. One such health outcome where this pathway seems particularly plausible is depression. Although one might expect a bidirectional longitudinal relationship between loneliness and depression, at least one study showed that loneliness predicted increased prospective depressive symptoms, but not the reverse, which hints at a causal path for loneliness to depression (Cacioppo, Hawkley, & Thisted, 2010; Cacioppo, Hughes et al., 2006). Our findings suggest that, during periods with insufficient social contact, lonely individuals may be particularly susceptible to anhedonia, one of two essential features of depression, which captures a loss of interest in activities the person previously enjoyed, resulting in a persistent and pervasive decline in positive affect. Third, in the present study, the participants were not acquainted with the audience members in the TSST. Future research could examine whether this element—the presence of novel individuals, as opposed to acquaintances, friends, or family—is critical to observing that the presence of others influences positive affect as a function of loneliness.

4.4. Limitations

Despite several strengths of this study, including a relatively large sample size for studies using lab-based stress induction, the use of a robust manipulation to elicit a cortisol response, and the use of clinical diagnostic interviews to exclude currently depressed individuals, there are also important limitations. First, our manipulation combined social context (being with others or alone) with evaluation. We expect that if the evaluative component of the manipulation was critical for loneliness, we would have observed effects on cortisol, which appears particularly sensitive to social evaluation (Dickerson & Kemeny, 2004). Future studies, however, should test a manipulation that, as much as possible, isolates social context to extend the present findings. Second, participants in our study were young adults in an adjustment stage characterized by heightened loneliness, particularly during college transition (Qualter et al., 2015; Sladek & Doane, 2015), and included a larger percentage of males. Future studies should employ samples of women or samples with equal gender distribution, and should investigate other developmental and

transitional periods to probe generalizability. Finally, our study was not designed to assess the influence of different subtypes of loneliness (intimate, social, and affiliative; McWhirter, 1990; Ernst & Cacioppo, 1999).

4.5. Conclusion

Trait loneliness is associated with numerous adverse mental and physical health outcomes; the present study tested theoretical predictions of heightened negative affect and cortisol reactivity to social stress. In this study, loneliness was associated with heightened influence of the social context over positive affect, most prominently its subfacet Interest, but not over negative affect or cortisol. Among models of loneliness, this unpredicted outcome is most consistent with a social monitoring model in which loneliness enhances the salience of social information.

Conflicts of interest

The authors declared no conflicts of interest with respect to the authorship or the publication of this article.

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Protection of research participants

This study's protocol was approved by the University Institutional Review Board. All participants provided informed consent.

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