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Testing an interpersonal risk pathway to suicidal ideation in adolescence: linking neural, psychological, and sociometric indices of socially relevant factors

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Abstract

Sensitivity to the social environment is linked to suicidal ideation in adolescence, and little research has examined variance in neural functioning that may underlie this sensitivity and increase risk. Neural-based pathways to suicidal ideation are likely mediated by subjective experiences of the social environment. Loneliness is associated with both salience network connectivity and suicidal ideation. This longitudinal study tested whether greater salience network functional integration (i.e. global efficiency) in early adolescence, which may underlie hypervigilance to social experiences, predicts risk for future suicidal ideation via loneliness. Participants (N = 96; M_{age} = 12.94) completed a fMRI scan to measure resting-state salience network functional integration. Loneliness, suicidal ideation, and a sociometric measure of adolescents' real-world peer environment were assessed over several years. Greater salience network global efficiency was associated with suicidal ideation two years later via higher levels of loneliness approximately one year later, particularly for girls. Across boys and girls, the effect of salience network global efficiency on loneliness appeared stronger for youth experiencing relatively larger decreases in peer acceptance over the prior year. While findings should be interpreted as preliminary given the sample size, they suggest a possible social-developmental pathway from early-adolescent salience network integration to future vulnerability for loneliness and suicidal thinking.

Keywords: salience network, global efficiency, loneliness, suicidal ideation, adolescent

Suicidal ideation is prevalent among youth and often first emerges in adolescence (Gaylor et al. 2023). Research lags in testing multivariate risk models of suicidal ideation using longitudinal designs—particularly earlier in development, such as the transition to adolescence when rates of suicidal ideation increase dramatically (Franklin et al. 2017, Clayton et al. 2021). There is robust evidence that sensitivity to the interpersonal environment is linked to suicidal ideation during this period (Miller and Prinstein 2019). An important next step is to develop a more fine-grained, developmental understanding of for whom, and why, sensitivity to the social environment may give rise to suicidal thinking.

Interpersonal theories of suicide posit that subjective experiences of social isolation are key contributors to suicidal ideation, whereby aversive feelings of loneliness or 'thwarted belongingness' may influence desires for relief or escape in the form of suicidal thinking (Van Orden et al. 2012, O'Connor and Kirtley 2018). Youth who are more sensitive to their social environment may be vulnerable to feeling lonely and possibly to experience suicidal thoughts, particularly if their social contexts are more adverse. As peer relationships become more salient in adolescence, youth who are more sensitive to their social environment and who are less accepted by their school peers may feel lonely during this sensitive period of socioemotional development (Blakemore and Mills 2014). Girls may also be more vulnerable, as girls' peer contexts may particularly socialize connection-oriented goals and links between peer relationship intimacy and emotional functioning (Rose and Rudolph 2006). This study uses a unique longitudinal dataset to test hypotheses about how youths' social context interacts with neural sensitivity to the social environment to predict suicidal ideation in the adolescent transition (Fig. 1).

The salience network and sensitivity to the social environment

One index of individual-level sensitivity to the social environment is function of the brain's salience network. The salience network plays a key role in orienting and responding to salient stimuli in the environment (Menon and Uddin 2010) and is highly responsive to social stimuli in adults (Atzil et al. 2023). In adolescents, greater activation in salience network regions during socially relevant tasks may be indicators of adolescents' sensitivity to social context (Rosen et al. 2018, Telzer et al. 2021). In the resting state, functional patterns of the salience, among other, intrinsic brain networks are thought to predispose an individual to certain psychological or emotional states (Seeley et al. 2007, Do et al. 2022).

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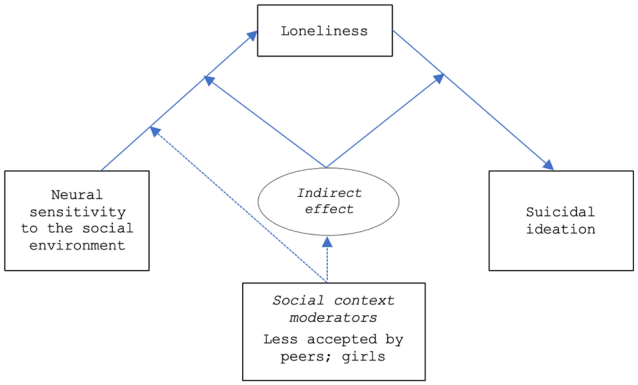

Figure 1. Hypothesized model of an association between neural sensitivity to the social environment and suicidal ideation through loneliness, as moderated by social context.

Examining salience network intrinsic connectivity at rest may therefore serve as a neurophysiological marker of more general predispositions towards sensitivity to the social environment. Indeed, studies have shown alterations in resting-state salience network connectivity among individuals with social anxiety (Pannekoek et al. 2013) and those exposed to high levels of social discrimination (Webb et al. 2022), whereby higher connectivity has been posited to underlie hypervigilance to social cues. Functional integration within the salience network at rest is also associated with alertness and vigilance to external stimuli more generally (Schneider et al. 2016). Consistent with this hypothesis, young adolescents (aged 11–14) with greater connectivity amongst nodes of the salience network at rest were more susceptible to both negative and positive peer norms: these adolescents reported engaging in riskier behaviours (e.g. driving with a risky driver) when they perceived that their peers did so too, but also reported more prosocial behaviours (e.g. helping a peer) when they perceived that their peers engaged in those behaviours (Do et al. 2022).

Metrics that use salience network topology to quantify network *efficiency* may be of particular interest. A more efficient salience network is characterized by higher overall potential for information transfer across distributed regions within the network (Rubinov and Sporns 2010). This may subserve more attuned and sensitive functioning of network-relevant processes, such as the detection of salient cues in the environment in the case of the salience network. Graph theory-based metrics of network organization can capture properties like network efficiency in ways that, compared to ROI-to-ROI connectivity approaches, may reflect important and meaningfully distinct aspects of the brain's functional complexity (Rubinov and Sporns 2010, Farahani et al. 2019).

One such graph theory-based metric is *global efficiency*, which quantifies the degree to which regions within a network are interconnected and provides a measure of how effectively information is integrated across the entire network. (This is in contrast to local efficiency, which measures integration between immediate neighbours of a given network node) (Rubinov and Sporns 2010). While related to metrics like resting-state functional connectivity (rsFC), salience network *global efficiency* provides meaningfully different information about network functioning and specifically captures the overall potential for information transfer (i.e. distributed processing) within a network (Bullmore and Bassett 2011). In quantifying a network's capacity for parallel information transfer between nodes, *global efficiency* may optimally capture the complexity of the brain's parallel information processing capabilities (Achard and Bullmore 2007). Given the role of the salience network in maintaining vigilance to external, including social, stimuli (Menon and Uddin 2010, Rosen et al. 2018, Atzil et al. 2023), higher salience network global efficiency may therefore be a hypothesized marker of neural 'sensitivity' to the social environment insofar as it indicates greater capacity for efficient information transfer across the entire network.

Loneliness

Higher salience network global efficiency, while potentially advantageous in certain contexts, may in more adverse social contexts underlie more sensitive detection of threats (e.g. peer rejection) or deficiencies (e.g. low peer acceptance) in the social environment in ways that increase vulnerability for loneliness. While this hypothesis has not yet been tested, theoretical models support its plausibility. Evolutionary theories of loneliness posit that loneliness is related to hypervigilance to social stimuli: vigilance to social, particularly ambiguous or negative, information may reinforce negative social expectancies or aversive self-focus and perpetuate loneliness as a self-protective response that serves to motivate reconnection (Cacioppo et al. 2009). This theoretical perspective is supported by studies showing that individuals who report feeling lonely show hypervigilance to social information, including social threats (Bangee et al. 2014, Cacioppo et al. 2015, 2016), and cross-sectional evidence of attentional and other cognitive (i.e. memory) biases in relation to social information among lonely individuals (Qualter et al. 2013, Igarashi 2025).

There is also evidence that loneliness is associated with alterations in salience network organization within the rest of the brain. In young adults, perceived social isolation (i.e. loneliness) is associated with increased functional connectivity between salience network regions—a pattern of greater within-network connectivity that may underlie hypervigilance to the social environment (Layden et al. 2017). Findings in adults largely support differences in intrinsic between-network connectivity, including between attentional networks that overlap with the salience network, and others involved in internally directed cognition (Mwilambwe-Tshilobo et al. 2019). Studies among lonely adults also find differences in functional integration within networks overlapping with the salience network (e.g. allostatic interoceptive network) (Ma et al. in prep) and altered between-network connectivity with the rest of the brain (Spreng et al. 2020).

Suicidal ideation and social context

These studies support the potential relevance of salience network integration to loneliness, though prior work has not examined this relation longitudinally in youth, nor tested whether this predicts the emergence of more acute psychological outcomes like suicidal thinking. Consistent with interpersonal theories of suicide, lonely youth may be at increased risk for suicidal ideation later in adolescence, whereby thoughts of suicide may represent coping responses to feelings of social disconnection that provide a sense of relief or escape from psychological pain (Millner et al. 2019, Coppersmith et al. 2023). Seemingly relevant to this hypothesis, a recent study found evidence of salience network cortical expansion in individuals with depression, including in children prior to the onset of depressive symptoms in adolescence (Lynch et al. 2024).

Neural sensitivity to the social environment may also be riskiest in certain peer contexts. Youth with greater salience network integration may be more likely to report feeling lonely, and potentially to develop suicidal thoughts, if their actual peer social contexts are more adverse (i.e. less accepted/more rejected by peers). Because loneliness captures a subjective experience of social disconnectedness, a measure that avoids conflating youths' subjective appraisals with objective metrics of their peer context is critical.

One such measure is sociometric *social preference*, which relies on peer nominations of how well one is liked among peers and is a robust index of peer social acceptance/rejection (Bierman and Wargo 1995). Widely used in developmental psychology, sociometric measures are rare among neuroscience studies yet provide an ecologically robust index of youths' peer social contexts.

It is also plausible that associations among neural sensitivity to social context, loneliness, and suicidal ideation are stronger for youth whose social-developmental contexts socialize connection-oriented goals. One way to test this is to consider the moderating role of sex: compared to boys, girls may be more motivated by connection-oriented goals and vulnerable to emotional distress to adverse social experiences (Rose and Rudolph 2006, Hankin et al. 2007). Rates of suicidal ideation are also higher among adolescent girls than boys (CDC 2023), and sensitivity to social-evaluative concerns has been linked to girls' elevated risk for internalizing symptoms (Rudolph and Conley 2005).

The current study

This study used a graph theory-based network approach to preliminarily examine salience network global efficiency as a hypothesized marker of sensitivity to the social environment. We tested models in which we hypothesized that greater salience network global efficiency in early adolescence would predict vulnerability for loneliness and future suicidal ideation, particularly among youth experiencing more real-world social disconnection (i.e. low peer acceptance) and particularly for girls.

We hypothesized that greater salience network global efficiency would predict a greater likelihood of suicidal ideation two years later, via higher levels of loneliness one year later (i.e. mediation). We then tested two moderated mediation models. We expected that the effects of salience network global efficiency on loneliness, and on suicidal ideation via loneliness, would be stronger among youth experiencing more adverse peer contexts. Loneliness is associated with both adverse social experiences (e.g. peer rejection) and perceived discrepancy between preferred and actual social experiences (Cacioppo et al. 2014). We therefore examined both single timepoint and one-year *change* in social preference as moderators to capture adverse peer experiences (i.e. high peer rejection/low peer acceptance) and relative change in peer experiences (i.e. difference or 'discrepancy' from the prior year, reflective of relative declines in acceptance/increases in rejection), respectively. Separately, we also tested the hypothesis that the effect of salience network global efficiency on loneliness and suicidal ideation via loneliness would be stronger among girls (vs. boys).

Methods

Participants

Participants came from a larger longitudinal study of youth, recruited from public middle schools in the southeast United States, who participated in a fMRI scan and were at least 11 years, 10 months old (i.e. eligibility). Enrollment exclusion criteria included a learning disability diagnosis, history of seizures or head trauma, or dental work involving metal. Of the 171 participants who participated in the scan, 54 were excluded from analyses due to missing and/or lack of useable resting-state scan data (see Supplement) and 21 were excluded due to missing suicidal ideation outcome data (i.e. Time 3), yielding a current sample of 96 youth, ages 11–14 years at time of scan (M = 12.94 years, SD = 0.54). The sample was approximately half (53.1%) female (46.9% male; assigned sex). At baseline, all participants indicated the same response for biological sex as for gender. Based on data available at follow-ups, two participants later indicated a different gender than that endorsed at baseline (i.e., change in gender identity). We use the term 'assigned sex' throughout but note that, at baseline, participants' gender identity matched sex assigned at birth, and also matched for the vast majority of participants longitudinally. The sample was relatively diverse with regards to race and ethnicity (Table 1), although we did not hypothesize differences based on race or ethnicity.

Self-report and sociometric data were obtained from the larger longitudinal study, in which participants completed self-report measures of loneliness, suicidal ideation, and depressive symptoms, and a sociometric nomination procedure, in school at one or more timepoints across one-year intervals. The fMRI scan timepoint served as the baseline. We modelled loneliness and sociometric data at Time 2 (scan to Time 2 months: M = 15.61, SD = 4.73) and suicidal ideation data at Time 3 (Time 2 to Time 3 months: M = 11.13, SD = 0.54), such that there was temporal precedence in testing associations among baseline salience network global efficiency, loneliness and social preference (Time 2), and suicidal ideation (Time 3).

Measures

Loneliness

Loneliness was assessed using a 5-item adaptation of the Loneliness and Social Dissatisfaction Questionnaire (Cassidy and Asher 1992, Vanhalst et al. 2017). Participants rated the extent to which they had experienced lonely feelings (e.g. 'I was lonely') in the prior year on a 5-point scale (1 = *Never*, 2 = *Rarely*, 3 = *Sometimes*, 4 = *Often*, 5 = *Very often*; Cronbach's $\alpha = .92$), with higher scores reflecting higher levels of loneliness.

Suicidal ideation

Suicidal ideation was assessed using an 8-item measure (Heilbron and Prinstein 2010) asking about past-year frequency of multiple types of suicidal thoughts (e.g. 'I thought it would be better if I were not alive'; 'I wished I were dead'; 'I thought about how I would kill myself') on a 5-point Likert scale (1 = *Never*, 2 = *A few times*, 3 = *Couple of times a month*, 4 = *About once a week*, 5 = *Almost every day*). The measure was used to create a binary suicidal ideation outcome (i.e. presence/absence) based on statistical (e.g. minimal variance beyond responses endorsing more passive thoughts 'a few times') and other measurement-related considerations. Specifically, suicidal ideation in this sample was most reflective of more passive suicidal thoughts, endorsed at lower frequencies. That the suicidal ideation measure did not clearly distinguish suicidal ideation severity (e.g. active vs. passive) from frequency also limited the extent to which continuous scores reflected a clear and/or intuitive continuum of suicidal ideation 'acuity'. A binary outcome was therefore selected to better reflect the nature of suicidal ideation in the sample and to facilitate clearer interpretation of results.

Table 1. Participant demographics by race and ethnicity.

Race	Ethnicity	
	Hispanic/ Latinx *N* (%)	Not Hispanic/ Latinx *N* (%)
White	9 (9.4%)	34 (35.4%)
Black/African American	1 (1.0%)	18 (18.8%)
American Indian/Alaska Native	2 (2.1%)	1 (1.0%)
Asian	0 (0%)	1 (1.0%)
Other	17 (17.7%)	0 (0%)
Unspecified	1 (1.0%)	0 (0%)
Mixed race	1 (1.0%)	11 (11.5%)

Social preference

Social preference was determined using a standard, school-based sociometric peer nomination procedure (Coie and Dodge 1983) (see Supplement), with higher scores indicative of being more well-liked (i.e. acceptance) and lower scores of being less well-liked (i.e. rejection) by peers.

Depressive symptoms

Depressive symptoms were assessed using an abbreviated, 9-item version of the Short Mood and Feelings Questionnaire (Messer et al. 1995) (see Supplement).

fMRI data acquisition and processing

Functional MRI data were acquired using a 3-Tesla Siemens Prisma MRI scanner. Participants completed an 8-min resting-state scan in which they were instructed to lie still and keep their eyes focused on a centred, white fixation cross on a black background. fMRI data acquisition and preprocessing are described in the Supplement. Postprocessing of resting-state scan data for subsequent functional connectivity analysis was conducted using *clpipe* (v1.4.3) (Henry et al. 2022) and included regression of head motion using 32 parameters (three translation parameters, three rotation parameters, CSF and WM timeseries, and their quadratic terms, first temporal derivatives, and temporal derivatives of quadratic terms), high pass filtering at .008 Hz, respiratory notch filtering at 0.31–0.43 Hz, intensity normalization, and scrubbing of motion-outlier timepoints with framewise displacement >0.3. Scans with a mean framewise-displacement of >.55 mm before scrubbing were also excluded.

fMRI data analysis

Region of interest (ROI) extraction was conducted on processed resting-state data using the Schaefer et al. (2018) 100-ROI cortical parcellation. The ROIs comprising the salience network were selected from that parcellation according to the Yeo et al. (2011) 7-network organization of the cortex. This resulted in a salience network composed of 12 ROIs, including hubs in the anterior insula and dorsal anterior cingulate cortex (Table 2, Fig. 2). Salience network connectivity matrices were obtained by submitting the ROI time series to an in-house script written and run in R (v4.2.1; described in Supplement). Salience network global efficiency was then computed using a MATLAB script from the Brain Connectivity Toolbox (BCT; v.2019-03-03) (Rubinov and Sporns 2010), which calculates the inverse average path length between all nodes in the network.

Table 2. Nodes included in the salience network used in this analysis, and their MNI coordinates.

Anatomical location/name	X	Y	Z
LH Parietal operculum	−59	−38	29
LH Anterior insula	−41	−1	−7
LH Anterior insula	−38	12	6
LH Dorsolateral prefrontal cortex	−30	44	30
LH Dorsal anterior cingulate cortex	−5	20	34
LH Dorsal posterior cingulate cortex	−11	−34	45
LH Premotor cortex	−6	4	62
RH Superior temporal gyrus	58	−42	13
RH Supramarginal gyrus	61	−26	27
RH Anterior insula	40	8	1
RH Dorsal posterior cingulate cortex	11	−31	45
RH premotor cortex	7	6	52

LH = left hemisphere; RH = right hemisphere; SN = salience network.

Analysis plan

Analyses were conducted in SPSS with the PROCESS macro (Hayes 2013). Bootstrap 95% confidence intervals were estimated from 5000 samples to evaluate the mediation effect significance. Suicidal ideation was modelled as a binary outcome (presence at Time 3), determined by endorsement of at least one suicidal ideation item at a frequency of 'a few times' or greater in the prior year. We first tested whether loneliness (Time 2) mediated the association between baseline salience network global efficiency and suicidal ideation presence (Time 3), with suicidal ideation presence and loneliness at baseline as covariates. We then examined moderators (i.e. social preference and social preference change; assigned sex) of the effect of salience network on loneliness, and the indirect effect on suicidal ideation via loneliness, in separate models with the same covariates. Baseline depressive symptoms were also controlled for in sensitivity analyses. Analyses are further described in the Supplement. This study was not preregistered, and materials are available from the authors upon request.

Results

Descriptive statistics

Descriptive statistics and correlations are presented in Table 3. The school-based sample reflected relatively low clinical severity. At Time 3, 38 youth endorsed suicidal ideation. Suicidal ideation 'acuity' (i.e. frequency/severity) was generally low (sum score M = 10.03, SD = 4.65), with 44.5% of participants who reported any suicidal ideation mostly endorsing one or two items at lower frequencies (Supplementary Table S1). The sample endorsed, on average, low levels of depressive symptoms across the study (Ms = 0.33–0.38). Age at time of scan was not correlated with salience network global efficiency, loneliness, or suicidal ideation and therefore not modelled as a covariate.

Mediation through loneliness

Higher baseline salience network global efficiency predicted higher levels of loneliness at Time 2 [$b = 1.645$, $P = .001$, 95% CI (0.664–2.627)], and higher levels of loneliness at Time 2 were related to greater likelihood of suicidal ideation at Time 3 [log odds = 0.136, $P = .01$, 95% CI (0.028–0.243)]. Bootstrap 95% CIs indicated a significant indirect effect (0.223, 95% CI [0.021–0.552]), supporting mediation from salience network global efficiency to suicidal ideation via loneliness. Results were similar when also controlling for depressive symptoms [e.g. significant indirect effect: 0.200, 95% CI (0.012–0.537)].

Moderation by social context

Social preference

Social preference at Time 2 did not moderate the direct effect of salience network global efficiency on loneliness nor the indirect effect on suicidal ideation (Supplement). However, the interaction of salience network global efficiency with *change* in social preference was associated with loneliness [$b = -1.457$, $P = .01$, 95% CI (−2.619 to −0.294)], such that greater salience network global efficiency was related to higher levels of loneliness at Time 2 at average [$b = 1.570$, $P < .01$, 95% CI (0.574–2.565)] and low [$b = 2.868$, $P < .01$, 95% CI (1.592–4.144)] levels of social preference change, where lower levels reflected relatively larger declines in peer acceptance/increases in peer rejection at Time 2 compared to the prior year (Fig. 3). Results were similar when using a regression-based change score. The indirect effect on suicidal ideation did not differ by level of social preference change (i.e. index of moderated mediation: 95%

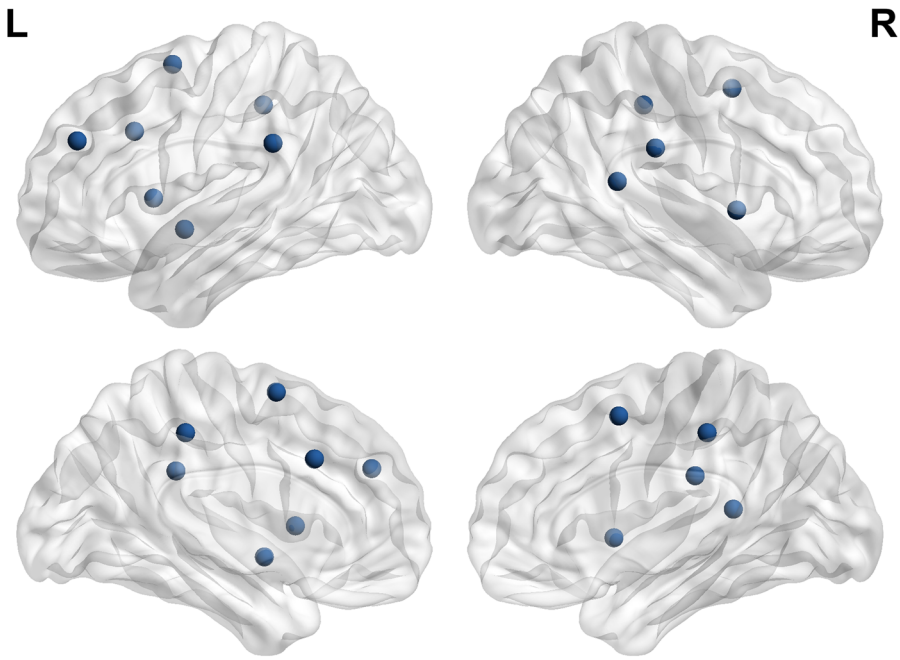

Figure 2. Medial and lateral views showing the nodes included in the salience network used in the present study.
Note. Depicts medial and lateral views of the left (L) and right (R) hemispheres. The network was visualized with the BrainNet Viewer (http://www.nitrc.org/projects/bnv/) (Xia et al. 2013).

Table 3. Descriptive statistics and bivariate correlations among study variables.

Variable	1	2	3	4	5	6	7	8	9
1. Salience network global efficiency	–								
2. Loneliness (Time 2)	0.39**	–							
3. SI presence (follow-up)	0.29**	0.46**	–						
4. SI presence (baseline)	0.22*	0.44**	0.33**	–					
5. Loneliness (baseline)	0.09	0.38**	0.33**	0.56**	–				
6. Social preference (Time 2)	–0.20	0.02	–0.13	–0.13	–0.18	–			
7. Social preference change[a]	–0.12	0.05	–0.09	–0.01	–0.05	0.44**	–		
8. Depressive symptoms (baseline)	0.13	0.44**	0.37**	0.51**	0.68**	–0.27**	–0.11	–	
9. Age (baseline)	0.03	0.08	0.15	0.15	0.18	0.10	0.21*	–0.28**	–
Mean	0.14	10.88	–	–	9.42	0.00	0.00	0.33	12.94
SD	0.04	5.45	–	–	4.62	1.00	0.89	0.41	0.54

SI = suicidal ideation. Correlations between continuous and categorical variables (i.e. SI presence) reflect point-biserial correlations. Statistics presented here used raw (i.e. unstandardized) values for salience network global efficiency. * $P < .05$; ** $P < .01$
[a]Scores reflecting one-year change in social preference ranged from –1.94 to 2.13.

CI (–0.642 to 0.031)]. Results were similar when controlling for depressive symptoms.

Sex

Assigned sex moderated the effect of salience network global efficiency on loneliness [$b = 3.172$, $P = .001$, 95% CI (1.261–5.084)] (Fig. 4). Greater salience network global efficiency was associated with higher levels of loneliness among girls [$b = 2.692$, $P < .01$, 95% CI (1.580–3.804)], but not boys [$b = –0.481$, $P = .54$, 95% CI (–2.041 to 1.080)]. The indirect effect on suicidal ideation via loneliness differed by sex (index of moderated mediation: 95% CI (0.048–1.090)] and was significant for girls [0.365, 95% CI (0.043–0.927)] but not boys [–0.065, 95% CI (–0.327 to 0.143)].

Supplemental analyses

We examined specificity to the salience network versus a control network (i.e. visual network); global efficiency of the salience network, above and beyond organization of the whole brain (i.e. whole-brain global efficiency); and global efficiency versus another functional integration metric (i.e. salience network average rsFC). Visual network global efficiency was not related to loneliness or suicidal ideation via loneliness across the sample, and moderation by social preference change was not significant but was for assigned sex (i.e. relations among girls). Results were similar to primary analyses for the salience network above and beyond whole-brain global efficiency (Supplement).

Results appeared specific to the global efficiency metric. Salience network average rsFC was not associated with loneliness [$b = 0.966$, $P = .06$, 95% CI (–0.055 to 1.987)], nor with suicidal ideation via loneliness [indirect effect coefficient = 0.146, 95% CI (–0.013 to 0.418)]. Interactions with social preference change [$b = 0.447$, $P = .16$, 95% CI (–0.172 to 1.065)] and assigned sex [$b = 1.721$, $P = .11$, 95% CI (–0.373 to 3.816)] did not predict loneliness. Assigned sex did not moderate the indirect effect on suicidal ideation (index of moderated mediation: 95% CI (–0.008 to 0.756)].

Discussion

Suicidal ideation often emerges in adolescence and is frequently linked to social factors, including subjective social disconnection (e.g. loneliness; Glenn et al. 2022) and exposure to adverse social

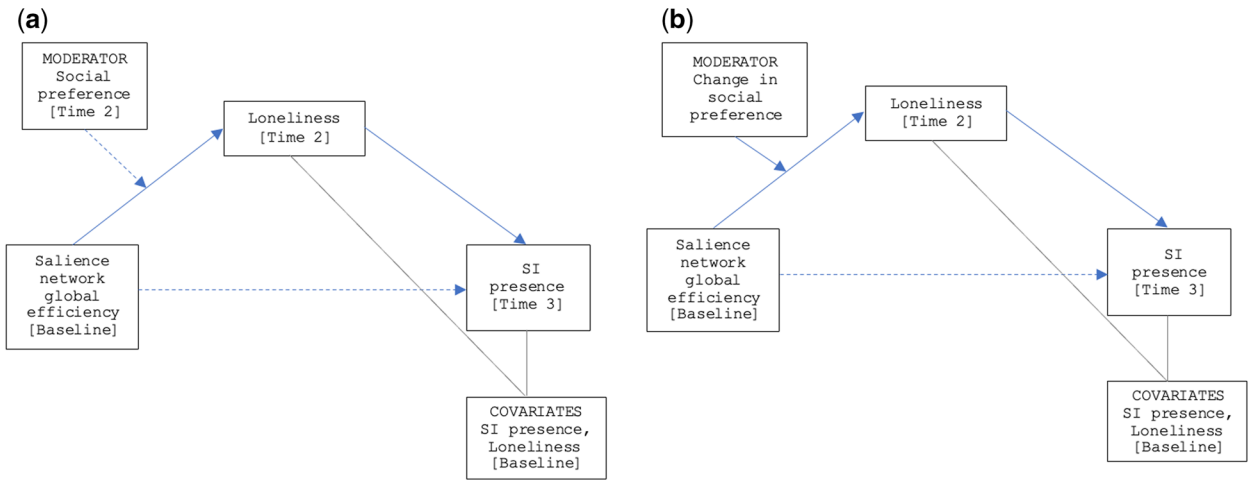

Figure 3. Longitudinal effect of salience network global efficiency on suicidal ideation via loneliness, with moderation by social preference (2a) and by change in social preference (2b).
Note. SI = suicidal ideation.

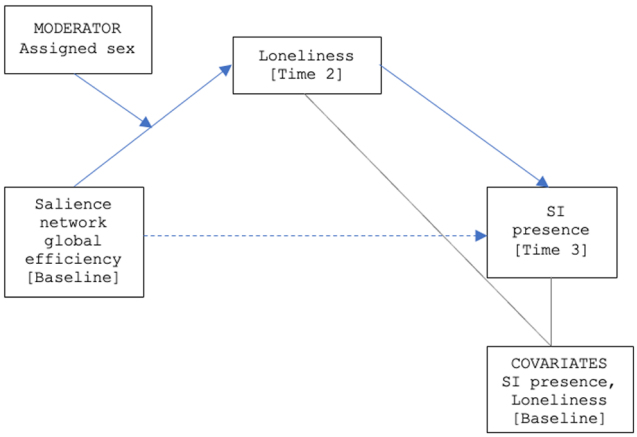

Figure 4. Longitudinal effect of salience network global efficiency on suicidal ideation via loneliness, with moderation by assigned sex.
Note. SI = suicidal ideation.

experiences (e.g. peer rejection; Cheek et al. 2020). Little research has examined neurophysiological markers of sensitivity to the social environment that may increase vulnerability for perceived social isolation and subsequent suicidal thinking. We conducted a preliminary examination of a hypothesized, longitudinal pathway between pre/early-adolescent neural network functional integration at rest (i.e. salience network global efficiency), loneliness, and suicidal ideation. Findings supported our primary hypothesis that greater salience network global efficiency would predict greater likelihood of suicidal ideation two years later through higher levels of loneliness one year later. Our hypothesized model appeared specific to girls and, across sexes, indicated the particular relevance of *changes* in the peer environment in moderating the effect of salience network global efficiency on loneliness one year later.

These findings should be interpreted as preliminary given the relatively small sample size, as discussed below. However, they hold promise in pointing to an aspect of neural functioning that may predispose certain youth to loneliness and suicidal thinking in the adolescent transition, particularly in combination with social context factors. While our mediation effect should be interpreted within the context of design (e.g. sample size) limitations, it is noteworthy that it was demonstrated prospectively, as there are few longitudinal studies of neural-based risk factors for suicidal ideation, particularly in youth and examining resting-state functional connectivity (vs. structural or task-based neural indices) (Schwartz et al. 2019, Auerbach et al. 2021, Patel et al. 2023). While preliminary, this builds on largely cross-sectional work implicating the salience network or salience-relevant regions in relation to both peer-related social processes and psychopathology in adolescents (Ordaz et al. 2018, Pelletier-Baldelli et al. 2023, 2024), as well as a prior longitudinal study of resting-state salience network connectivity and suicidal ideation in youth (Schwartz et al. 2019). Our findings also complement evidence of structural changes in relevant salience network hubs (e.g. insula) in relation to other self-injurious psychopathology in youth (Patel et al. 2023).

An important finding of this study was that salience network integration predicted loneliness one year later—a relation that has previously been shown cross-sectionally (Layden et al. 2017). One potential interpretation of this is that greater information processing capacity (i.e. higher global efficiency) of the salience network underlies more efficient detection of, and thus sensitivity to, social experiences in ways that impact internal experiences. A more efficiently connected salience network may process an overall greater amount of information about one's environment that renders this information more cognitively salient, predisposing youth to socio-emotional states related to perceptions of connectedness vis-a-vis others (Toller et al. 2018, Asakage and Nakano 2023). Indeed, neural attunement to salient social cues may underlie affective or subjective 'making-making processes' that reinforce associations between social information and self-views—particularly in adolescence, when peer-social feedback is especially likely to influence self-identity (Rodman et al. 2017).

This hypothesis may particularly be the case in contexts of adverse changes in youths' peer contexts. We found a moderating effect of one-year change in social preference: becoming less accepted/more rejected by peers appeared to intensify the effect of salience network integration on loneliness (though there was no moderation of the indirect effect on suicidal ideation). This is interesting when considering that loneliness can capture perceptions of social relationship inadequacy compared to one's expected or preferred social relationships (Cacioppo et al. 2006). A change in one's social preference (present vs. prior peer context) can thus be deleterious. Youth with neural sensitivity to their social environment may be vigilant to changes in peer relationships that influences loneliness, especially if changes are discrepant with

expectation or reflect declines in peer acceptance. Consistent with evolutionary theories, loneliness may represent a psychological response to adverse changes (e.g. threats, deficiencies) in the social environment that serves to motivate self-protective behaviours, like isolation or vigilance to rejection (Cacioppo et al. 2006, 2015).

Loneliness may in turn increase risk for coping in the form of suicidal thoughts, which are may fulfill a function of psychological escape from distress (Baumeister 1990, Millner et al. 2019). Interpersonal suicide theories posit that suicidal thoughts may arise for individuals who feel lonely and disconnected, as these feelings threaten fundamental needs for belonging (Van Orden et al. 2012, Baumeister and Leary 2017). Feeling disconnected from peers may be especially distressing and threatening to one's self-worth in adolescence, as youth increasingly rely on experiences with peers to inform views of themselves (Rodman et al. 2017, Buecker et al. 2025). Other contemporary suicide theories (e.g. Integrated-Motivational Volitional Model; O'Connor and Kirtley 2018) similarly identify social disconnectedness and thwarted belongingness as key contributors to suicidal ideation, and developmental theories emphasize sensitivity to peer-related experiences in explaining suicide vulnerability in the adolescent transition (Miller and Prinstein 2019).

The effects of salience network global efficiency on loneliness and suicidal ideation (via loneliness) also appeared specific to girls. Neural vigilance to salient information in the environment may particularly influence perceptions of oneself in relation to others (e.g. loneliness) for female youth, who may be more likely than boys to prioritize relationship-oriented goals and worry about feeling lonely (Kuperminc et al. 1997, Henrich et al. 2001). Our finding of a sex-specific effect is consistent with evidence that adolescent girls' self-concept and emotional functioning are more closely tied to relationships than for boys, and that girls are particularly vulnerable to experience distress related to interpersonal experiences (Rose and Rudolph 2006).

These differences may intensify in the adolescent transition due to both pubertal changes as well as gender-related socialization processes that may reinforce links between girls' perceptions of close relationships and their sense of identity (Henrich et al. 2001, Rose and Rudolph 2006), across racial and ethnic backgrounds (Fisher and Manstead 2000). Socialization processes may reinforce girls' reliance on peer relationships as sources of self-evaluation via more time spent discussing relationships compared boys (Moller et al. 1992), and social feedback that reinforces friendship maintenance and intimacy (Rose and Asher 1999). While the current sample did not reflect diverse gender identities, these socialization processes may be pertinent both to female gender-identifying youth and/or youth with other gender identities whose environments may reinforce similar socioemotional behaviours. Future work should consider gender-diverse samples to further explore how socialization processes interact with variance in neural (e.g. salience) network functioning to increase vulnerability for internalized distress like loneliness and suicidal thinking.

Supplemental analyses largely supported specificity of our findings to global efficiency (vs. average rsFC) of the salience (vs. visual) network, above and beyond whole-brain global efficiency. There was one exception: visual network global efficiency was similarly related to loneliness, and suicidal ideation via loneliness, in interaction with assigned sex (i.e. effects for girls). We interpret this post hoc finding cautiously but note that it appears consistent with evidence of sex differences in other visual network properties in relation to loneliness. A large-scale study of sex differentiation in brain volume patterns related to social outcomes found that visual sensory network volume differed in lonely (vs. isolated) women, but not in men, tentatively suggesting that appraisal of the visual social environment may be associated with loneliness in females (Kiesow et al. 2020). For girls, functional integration within the salience, and visual, networks may thus underlie sensitivity to the social environment in ways that influence loneliness. The female-specific effect for the visual network in our supplemental analyses also appears consistent with cross-sectional associations between loneliness and visual attention biases to negative social information in eye-tracking and brain-based studies (Cacioppo et al. 2009, 2016, Qualter et al. 2013, Spithoven et al. 2017).

Our different findings for salience network global efficiency and average rsFC also warrant comment. These metrics are related, but global efficiency provides meaningfully different information about a network's topology. While average rsFC quantifies the average strength of connections between nodes in a network, global efficiency provides information about efficiency of information transfer across the entire network by quantifying how easily information can travel among all nodes. For context, in this sample, salience network global efficiency and average rsFC were moderately correlated ($r = 0.51$). While average rsFC is a measure of how closely the BOLD signals covary in nodes of the network, global efficiency is based on path length and is a measure of how many steps are required to get from each node to each other node via existing, above-threshold paths (Rubinov and Sporns 2010, Farahani et al. 2019). (See Zuo et al. (2012) for further description of graph theory-based metrics of brain connectivity and comparison with metrics more widely used in the functional connectivity literature so far). Thus, in the case of our findings, processes related more specifically to capacity of the salience network to integrate information *across* all network regions—how effectively the network communicates across its components, versus a focus on the average of relations between a given region with other, individual regions in the network (e.g. rsFC)—may thus be pertinent to risk. As hypothesized, this may subserve more sensitive detection of salient external (e.g. social) information and efficient integration with internal processing, given the role of the salience network in switching between networks involved in externally oriented attention and those implicated in internal, self-focused processing (Menon and Uddin 2010). In other words, global efficiency may index aspects of salience network functional integration (e.g. topological complexity; parallel information transfer among nodes) that underlies, perhaps more closely or differently than rsFC, a sensitive 'feedback loop' between the external environment and internal processing that contributes to loneliness and suicidal ideation.

Our study had several important limitations. While our sample was larger than several prior studies of neural network functional connectivity and loneliness (Layden et al. 2017), larger samples will be critical to rigorously examine brain–behaviour associations. Replication in larger samples is important because smaller samples may be more vulnerable to sampling variability and are comparatively less powered to detect brain–behaviour associations (Marek et al. 2022). Future work in large consortium neuroimaging datasets will provide an important complement to smaller studies such as this. Grounded in developmental psychopathology, this study was well-positioned to preliminarily test theoretically motivated hypotheses regarding a neural-based risk pathway to suicidal ideation, which can inform work in larger datasets that may offer multiple timepoints of neuroimaging data to test these hypotheses using within-person designs (Pritschet et al. 2020, Gratton et al. 2022).

Second, our sociometric social preference measure was ecologically robust and novel for suicide research, but nevertheless captured one social environment (i.e. school-based peers). Other social contexts are pertinent to suicidal ideation in adolescence and warrant consideration (see Supplement). The measure could not shed

light on specific mechanisms related to social preference change that may moderate risk, and future studies might also consider other approaches for modelling change (McCormick and Bauer 2024). Third, our sample lacked gender-related diversity. Different aspects of gender influence youths' social self-perceptions and peer relationships (Else-Quest et al. 2012; Hines 2020), and testing our hypotheses in relation to multiple aspects of gender identity and expression may help understand the influence of gender-related socialization processes. Finally, suicidal ideation severity was relatively low in this community-based sample. Replication in clinically acute samples is needed to explore how our model relates to passive versus active, and infrequent versus frequent, suicidal thinking. This study nevertheless provides an important, albeit preliminary, contribution by showing a longitudinal association between a hypothesized neural index of sensitivity to the social environment and suicidal ideation, as mediated by psychological experiences (i.e. loneliness) and moderated by social context (i.e. peer acceptance; assigned sex).

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Author contributions

Eva H. Telzer, Kristen A. Lindquist, and Mitchell J. Prinstein designed and performed research; Olivia H. Pollak, Natalie G. Frye, Tehila Nugiel, and Jessica R. Cohen analyzed the data and/or assisted in data processing; O.H.P. and N.G.F wrote the manuscript; Kristen A. Lindquist, Mitchell J. Prinstein, Eva H. Telzer, Tehila Nugiel, and Jessica R. Cohen edited and reviewed the manuscript.

Supplementary data

Supplementary data is available at *SCAN* online.

Conflict of interest

The authors report no relevant conflicts of interest.

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References

Achard S, Bullmore E. Efficiency and cost of economical brain functional networks. *PLoS Comput Biol.* 2007;**3**:e17.

Asakage S, Nakano T. The salience network is activated during self-recognition from both first-person and third-person perspectives. *Hum Brain Mapp* 2023;**44**:559–70.

Atzil S, Satpute AB, Zhang J *et al.* The impact of sociality and affective valence on brain activation: a meta-analysis. *Neuroimage* 2023;**268**:119879.

Auerbach RP, Pagliaccio D, Allison GO *et al.* Neural correlates associated with suicide and nonsuicidal self-injury in youth. *Biol Psychiatry* 2021;**89**:119–33.

Bangee M, Harris RA, Bridges N *et al.* Loneliness and attention to social threat in young adults: Findings from an eye tracker study. *Pers Individ Dif* 2014;**63**:16–23.

Baumeister RF. Suicide as escape from self. *Psychol Rev* 1990;**97**:90–113.

Baumeister RF, Leary MR. The need to belong: Desire for interpersonal attachments as a fundamental human motivation. *Psychol Bull* 1995;**117**:497–529.

Bierman KL, Wargo JB. Predicting the longitudinal course associated with aggressive-rejected, aggressive (nonrejected), and rejected (nonaggressive) status. *Dev Psychopathol* 1995;**7**:669–82.

Blakemore SJ, Mills KL. Is adolescence a sensitive period for sociocultural processing? *Annu Rev Psychol* 2014;**65**:187–207.

Buecker S, Doll J, Abrantes Diaz S *et al.* Self-esteem and suicidal thoughts and behaviors: a meta-analytic review. *Clin Psychol Sci* 2025;**21677026241308163**:

Bullmore ET, Bassett DS. Brain graphs: graphical models of the human brain connectome. *Annu Rev Clin Psychol* 2011;**7**:113–40.

Cacioppo JT, Cacioppo S, Cole SW *et al.* Loneliness across phylogeny and a call for comparative studies and animal models. *Perspect Psychol Sci* 2015;**10**:202–12.

Cacioppo JT, Hawkley LC, Ernst JM *et al.* Loneliness within a nomological net: an evolutionary perspective. *J Res Pers* 2006;**40**:1054–85.

Cacioppo JT, Norris CJ, Decety J *et al.* In the eye of the beholder: individual differences in perceived social isolation predict regional brain activation to social stimuli. *J Cogn Neurosci* 2009;**21**:83–92.

Cacioppo S, Balogh S, Cacioppo JT. Implicit attention to negative social, in contrast to nonsocial, words in the stroop task differs between individuals high and low in loneliness: Evidence from event-related brain microstates. *Cortex* 2015;**70**:213–33.

Cacioppo S, Bangee M, Balogh S *et al.* Loneliness and implicit attention to social threat: a high-performance electrical neuroimaging study. *Cogn Neurosci* 2016;**7**:138–59.

Cacioppo S, Capitanio JP, Cacioppo JT. Toward a neurology of loneliness. *Psychol Bull* 2014;**140**:1464–504.

Cassidy J, Asher SR. Loneliness and peer relations in young children. *Child Dev* 1992;**63**:350–65.

Centers for Disease Control and Prevention. *Youth Risk Behavior Survey: Data Summary & Trends Report, 2011–2021*. U.S. Department of Health and Human Services; 2023.

Cheek SM, Reiter-Lavery T, Goldston DB. Social rejection, popularity, peer victimization, and self-injurious thoughts and behaviors among adolescents: a systematic review and meta-analysis. *Clin Psychol Rev* 2020;**82**:101936.

Clayton MG, Pollak OH, Owens SA *et al.* Advances in research on adolescent suicide and a high priority agenda for future research. *J Res Adolesc* 2021;**31**:1068–96.

Coie JD, Dodge KA. Continuities and changes in children's social status: a five-year longitudinal study. *Merrill-Palmer Q* 1983;**29**:261–82.

Coppersmith DDL, Millgram Y, Kleiman EM *et al.* Suicidal thinking as affect regulation. *J Psychopathol Clin Sci* 2023;**132**:385–95.

Do KT, McCormick EM, Prinstein MJ *et al.* Intrinsic connectivity within the affective salience network moderates adolescent susceptibility to negative and positive peer norms. *Sci Rep* 2022;**12**:17463.

Else-Quest NM, Higgins A, Allison C *et al.* Gender differences in self-conscious emotional experience: a meta-analysis. *Psychol Bull* 2012;**138**:947–81.

Farahani FV, Karwowski W, Lighthall NR. Application of graph theory for identifying connectivity patterns in human brain networks: a systematic review. *Front Neurosci* 2019;**13**:585.

Fisher AH, Manstead AS. The relation between gender and emotions in different cultures. In: Fischer AH (ed.), *Gender and Emotion: Social Psychological Perspectives*. Cambridge University Press, 2000, 71–94

Franklin JC, Ribeiro JD, Fox KR *et al.* Risk factors for suicidal thoughts and behaviors: a meta-analysis of 50 years of research. *Psychol Bull* 2017;**143**:187–232.

Gaylor EM, Krause KH, Welder LE *et al.* Suicidal thoughts and behaviors among high school students—youth risk behavior survey, United States, 2021. *MMWR Suppl* 2023;**72**:45–54.

Glenn CR, Kleiman EM, Kandlur R *et al.* Thwarted belongingness mediates interpersonal stress and suicidal thoughts: an intensive longitudinal study with high-risk adolescents. *J Clin Child Adolesc Psychol* 2022;**51**:295–311.

Gratton C, Nelson SM, Gordon EM. Brain-behavior correlations: Two paths toward reliability. *Neuron* 2022;**110**:1446–9.

Hankin BL, Mermelstein R, Roesch L. Sex differences in adolescent depression: stress exposure and reactivity models. *Child Dev* 2007;**78**:279–95.

Hayes AF. (2013). Introduction to mediation, moderation, and conditional process analysis: A regression-based approach. The Guilford Press.

Heilbron N, Prinstein MJ. Adolescent peer victimization, peer status, suicidal ideation, and nonsuicidal Self-Injury: Examining concurrent and longitudinal associations. *Merrill Palmer Q (Wayne State Univ Press)* 2010;**56**:388–419.

Henrich CC, Blatt SJ, Kuperminc GP *et al.* Levels of interpersonal concerns and social functioning in early adolescent boys and girls. *J Pers Assess* 2001;**76**:48–67.

Henry T, Asciutto W, Callenberg, K, Kaduffy. github.com/cohenlabUNC/clpipe: clpipe v1.4.3 (v1.4.3). Zenodo, 2022. 10.5281/zenodo.6412959.

Hines M. Neuroscience and sex/gender: Looking back and forward. *J Neurosci* 2020;**40**:37–43.

Igarashi T. Loneliness and socioemotional memory. *Br J Soc Psychol* 2025;**64**:e12783.

Kiesow H, Dunbar RI, Kable JW *et al.* 10,000 Social brains: sex differentiation in human brain anatomy. *Sci Adv* 2020;**6**:eaaz1170.

Kuperminc GP, Blatt SJ, Leadbeater BJ. Relatedness, self-definition, and early adolescent adjustment. *Cognit Ther Res* 1997;**21**:301–20.

Layden EA, Cacioppo JT, Cacioppo S *et al.* Perceived social isolation is associated with altered functional connectivity in neural networks associated with tonic alertness and executive control. *Neuroimage* 2017;**145**:58–73.

Lynch CJ, Elbau IG, Ng T *et al.* Frontostriatal salience network expansion in individuals in depression. *Nature* 2024;**633**:624–33.

Ma R, West T, Casconne A *et al.* (in prep). The effects of age and loneliness on static and dynamic organization of the brain's allostatic interoceptive network

Marek S, Tervo-Clemmens B, Calabro FJ *et al.* Reproducible brain-wide association studies require thousands of individuals. *Nature* 2022;**603**:654–60.

McCormick EM, Bauer DJ. How should we model the effect of "change"-or should we? *Psychol Methods*2024.

Menon V, Uddin LQ. Saliency, switching, attention and control: a network model of insula function. *Brain Struct Funct* 2010;**214**:655–67.

Messer SC, Angold A, Costello EJ *et al.* Development of a short questionnaire for use in epidemiological studies of depression in children and adolescents: Factor composition and structure across development. *Int J Methods Psychiatr Res* 1995;**5**:251–62.

Miller AB, Prinstein MJ. Adolescent suicide as a failure of acute stress-response systems. *Annu Rev Clin Psychol* 2019;**15**:425–50.

Millner AJ, den Ouden HEM, Gershman SJ *et al.* Suicidal thoughts and behaviors are associated with an increased decision-making bias for active responses to escape aversive states. *J Abnorm Psychol* 2019;**128**:106–18.

Moller LC, Hymel S, Rubin KH. Sex typing in play and popularity in middle childhood. *Sex Roles* 1992;**26-26**:331–53.

Mwilambwe-Tshilobo L, Ge T, Chong M *et al.* Loneliness and meaning in life are reflected in the intrinsic network architecture of the brain. *Soc Cogn Affect Neurosci* 2019;**14**:423–33.

O'Connor RC, Kirtley OJ. The integrated motivational-volitional model of suicidal behaviour. *Philos Trans R Soc B* 2018;**373**:20170268

Ordaz SJ, Goyer MS, Ho TC *et al.* Network basis of suicidal ideation in depressed adolescents. *J Affect Disord* 2018;**226**:92–9.

Pannekoek JN, Veer IM, van Tol MJ *et al.* Resting-state functional connectivity abnormalities in limbic and salience networks in social anxiety disorder without comorbidity. *Eur Neuropsychopharmacol* 2013;**23**:186–95.

Patel KK, Sheridan MA, Bonar AS *et al.* A preliminary investigation into cortical structural alterations in adolescents with nonsuicidal self-injury. *Psychiatry Res Neuroimaging* 2023;**336**:

Pelletier-Baldelli A, Sheridan MA, Glier S *et al.* Social goals in girls transitioning to adolescence: associations with psychopathology and brain network connectivity. *Soc Cogn Affect Neurosci* 2023;**18**:

Pelletier-Baldelli A, Sheridan MA, Rudolph MD *et al.* Brain network connectivity during peer evaluation in adolescent females: Associations with age, pubertal hormones, timing, and status. *Dev Cogn Neurosci* 2024;**66**:101357.

Pritschet L, Santander T, Taylor CM *et al.* Functional reorganization of brain networks across the human menstrual cycle. *Neuroimage* 2020;**220**:117091.

Qualter P, Rotenberg K, Barrett L *et al.* Investigating hypervigilance for social threat of lonely children. *J Abnorm Child Psychol* 2013;**41**:325–38.

Rodman AM, Powers KE, Somerville LH. Development of self-protective biases in response to social evaluative feedback. *Proc Natl Acad Sci USA* 2017;**114**:13158–63.

Rose AJ, Asher SR. Children's goals and strategies in response to conflicts within a friendship. *Dev Psychol* 1999;**35**:69–79.

Rose AJ, Rudolph KD. A review of sex differences in peer relationship processes: potential trade-offs for the emotional and behavioral development of girls and boys. *Psychol Bull* 2006;**132**:98–131.

Rosen ML, Sheridan MA, Sambrook KA *et al.* Salience network response to changes in emotional expressions of others is heightened during early adolescence: relevance for social functioning. *Dev Sci* 2018;**21**:e12571.

Rubinov M, Sporns O. Complex network measures of brain connectivity: uses and interpretations. *Neuroimage* 2010;**52**:1059–69.

Rudolph KD, Conley CS. The socioemotional costs and benefits of social-evaluative concerns: do girls care too much?*J Pers* 2005;**73**:115–38.

Schaefer A, Kong R, Gordon EM *et al.* Local-Global parcellation of the human cerebral cortex from intrinsic functional connectivity MRI. *Cereb Cortex* 2018;**28**:3095–114.

Schneider M, Hathway P, Leuchs L *et al.* Spontaneous pupil dilations during the resting state are associated with activation of the salience network. *Neuroimage* 2016;**139**:189–201.

Schwartz J, Ordaz SJ, Ho TC *et al.* Longitudinal decreases in suicidal ideation are associated with increases in salience network coherence in depressed adolescents. *J Affect Disord* 2019;**245**:545–52.

Seeley WW, Menon V, Schatzberg AF *et al.* Dissociable intrinsic connectivity networks for salience processing and executive control. *J Neurosci* 2007;**27**:2349–56.

Spithoven AW, Bijttebier P, Goossens L. It is all in their mind: a review on information processing bias in lonely individuals. *Clin Psychol Rev* 2017;**58**:97–114.

Spreng RN, Dimas E, Mwilambwe-Tshilobo L *et al.* The default network of the human brain is associated with perceived social isolation. *Nat Commun* 2020;**11**:6393.

Telzer EH, Jorgensen NA, Prinstein MJ *et al.* Neurobiological sensitivity to social rewards and punishments moderates link between peer norms and adolescent risk taking. *Child Dev* 2021;**92**:731–45.

Toller G, Brown J, Sollberger M *et al.* Individual differences in socio-emotional sensitivity are an index of salience network function. *Cortex* 2018;**103**:211–23.

Van Orden KA, Cukrowicz KC, Witte TK *et al.* Thwarted belongingness and perceived burdensomeness: construct validity and psychometric properties of the interpersonal needs questionnaire. *Psychol Assess* 2012;**24**:197–215.

Vanhalst J, Gibb BE, Prinstein MJ. Lonely adolescents exhibit heightened sensitivity for facial cues of emotion. *Cogn Emot* 2017;**31**:377–83.

Webb EK, Bird CM, deRoon-Cassini TA *et al.* Racial discrimination and Resting-State functional connectivity of salience network nodes in Trauma-Exposed black adults in the United States. *JAMA Network Open*, 2022;**5**:e2144759.

Xia M, Wang J, & He Y. (2013). BrainNet Viewer: a network visualization tool for human brain connectomics. *PloS one* **8**: e68910.

Yeo BT, Krienen FM, Sepulcre J *et al.* The organization of the human cerebral cortex estimated by intrinsic functional connectivity. *J Neurophysiol* 2011;**106**:1125–65.

Zuo X-N, Ehmke R, Mennes M *et al.* Network centrality in the human functional connectome. *Cereb Cortex* 2012;**22**:1862–75.