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Mind-Wandering in Adolescents Predicts Worse Affect and Is Linked to Aberrant Default Mode Network–Salience Network Connectivity

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Objective: Understanding the fluctuating emotional and cognitive states of adolescents with depressive symptoms requires fine-grained and naturalistic measurements. This study used ecological momentary assessment (EMA) to investigate the affective correlates and consequences of mind-wandering in adolescents with anhedonia (AH) and typically developing (TD) controls. In addition, we examined the association between mind-wandering and resting state functional connectivity between the medial prefrontal cortex (mPFC), a core hub of the default mode network (DMN) linked to internally oriented mentation, and networks linked to attentional control (dorsal attention network [DAN]) and affect/salience detection (salience network [SN]).

Method: A total of 65 adolescents, aged 12 to 18 years (TD = 36; AH = 29), completed a resting state functional magnetic resonance imaging scan and subsequently used a smartphone application for ecological momentary assessment (EMA) data collection (2−3 times/d for 5 days). Each survey (N = 678) prompted adolescents to report on their current positive and negative affect (PA and NA), cognition, and activity.

Results: The frequency of mind-wandering was higher for AH (70.0% of EMA samples) relative to TD (59.2%) participants, and the participants with AH were more likely to mind-wander to unpleasant content. Mind-wandering was associated with higher concurrent NA, even when controlling for plausible confounds (eg, current activity, social companion, rumination). Time-lagged analyses revealed a bidirectional association between mind-wandering and PA. Greater levels of mind-wandering within the AH group were associated with stronger mPFC-SN/DAN connectivity.

Conclusion: Rates of mind-wandering were high, especially among adolescents with anhedonia, and predicted worse affect. The relation between mind-wandering and enhanced mPFC-SN coupling may reflect heightened bottom-up influence of affective and sensory salience on DMN-mediated internally oriented thought.

Key words: ecological momentary assessment, mind-wandering, anhedonia, adolescents, functional connectivity

J Am Acad Child Adolesc Psychiatry 2021;60(3):377–387.

Experience sampling studies indicate that we spend approximately 30% to 50% of our waking hours thinking about something other than what we are doing (ie, mind-wandering).[1–3] Episodes of mind-wandering are frequently unintentional, and individuals are often not metacognitively aware that their mind is wandering.[4] In a now highly cited experience sampling study in unselected adults, Killingsworth and Gilbert[3] reported that participants were mind-wandering nearly half (47%) of the time that they were surveyed. Not only was mind-wandering highly prevalent, but participants reported being less happy during episodes of mind-wandering than when focused on their current activity (but see Welz *et al.*[5]). Consistent with a putative causal role of mind-wandering contributing to lower mood, time-lagged analyses revealed that mind-wandering predicted lower happiness at the next experience sampling timepoint, but not vice versa. In contrast to the above findings, other observational[6] and mood-induction[7] studies suggest that lower mood may be a cause—rather than a mere consequence—of mind-wandering.

The mixed findings on the relation between mind-wandering and mood are likely due, at least in part, to the fact that mind-wandering is a highly heterogeneous cognitive construct. The valence (eg, negative, positive, or neutral thought content), temporal-orientation (eg, thinking about the past versus the future), and self-referential quality (eg, thoughts related to the self versus others) of mind-wandering may have a substantial influence on its affective consequences. For example, rumination

represents one form of mind-wandering characterized by negatively valenced, past-oriented, and typically self-referential thoughts, which has been repeatedly shown to predict worse affect.[8,9] In contrast, other forms of mind-wandering (eg, related to creative thinking or anticipatory pleasure) may produce positive outcomes.[10] Such findings highlight the importance of considering cognitive content as a moderator of the relation between mind-wandering and affect. Relatedly, within mind-wandering studies that rely on unselected samples,[3] it is often unclear to what extent the pattern of findings is influenced by depression, a disorder characterized by rumination. More specifically, depression may represent a plausible third variable confound of the relation between mind-wandering and worse affect, insofar as individuals with elevated levels of depressive symptoms report both higher levels of mind-wandering (eg, due to a greater propensity to ruminate and/or to executive/attentional control deficits)[11] and worse affect, but mind-wandering itself does not cause worse affect. Thus, it is important to examine the moderating influence of depression on the relation between mind-wandering and affect. Finally, the bulk of the mind-wandering literature has relied on adult samples. Accordingly, research is needed to examine the frequency, content, and affective correlates of mind-wandering in youth, in particular given evidence of higher levels of rumination[12-14] and mind-wandering[15-17] (but see Stawarczyk *et al.*[18]) among adolescents relative to children or adults.

Neural Substrates of Mind-Wandering

Given its link to internally oriented mental processes and self-referential thinking, it is not surprising that the default mode network (DMN) has received considerable attention in the mind-wandering literature.[10] Several DMN regions, including the posterior cingulate cortex (PCC) and medial prefrontal cortex (mPFC), have been associated with the tendency to mind-wander.[19] The mPFC, a core hub of the DMN, has been strongly implicated in mind-wandering and self-referential processing.[19,20] Consistent with meta-analytic evidence from functional neuroimaging studies indicating the involvement of the mPFC in mind-wandering,[19] inhibitory (ie, cathodal) transcranial direct current stimulation (tDCS) of the mPFC, but not occipital or sham tDCS, has been shown to reduce mind-wandering, but only in men.[21] In addition, individuals with lesions to the ventral mPFC mind-wander significantly less than control participants with lesions elsewhere and healthy individuals.[22]

In contrast to the DMN, the dorsal attention network (DAN), consisting of a distributed array of brain regions including the intraparietal sulcus (IPS) and frontal eye field (FEF), is preferentially engaged during externally oriented attention.[23] The DAN may serve to attenuate mind-wandering by constraining attention toward the external environment.[10,24] In addition, the salience network (SN), which includes the anterior insula and dorsal anterior cingulate cortex (dACC), has been linked to the automatic bottom-up detection of both internal and external salient events, and may coordinate switching between the DMN (internally oriented attention) and DAN (externally oriented attention).[10] For example, SN-DMN coupling may be responsible for the saliency of negative affect "capturing" attention and shifting it away from the task at hand and toward internally oriented thoughts.

It is important to note that abnormalities in each of the above networks have been linked with depression and anhedonia, including increased connectivity within the DMN and between the DMN and SN,[25-28] as well as reduced connectivity between the DMN and DAN.[29,30] Some of these abnormalities may be attributable to heightened rumination, a cognitive hallmark of depression. Like mind-wandering, rumination is a form of task-unrelated thinking. Indeed, recent studies have shown that higher levels of rumination (among individuals with depressive symptoms, but not healthy controls) are associated with functional connectivity between the mPFC (of the DMN) and insula (of the SN).[31,32]

Based on the literature summarized above, and to address a gap in the literature, we examined the frequency, content, and affective correlates of mind-wandering in a sample of typically developing (TD) adolescents and a group with elevated anhedonia and depressive symptoms (adolescents with anhedonia [AH]). In addition, within each of these groups, we examined the relation between mind-wandering and resting state functional connectivity between the medial prefrontal cortex (mPFC), a core hub of DMN linked to internally oriented mentation and self-referential processing, with other regions of the DMN, DAN, and SN. We predicted that participants with AH would exhibit higher levels of mind-wandering (in particular, to negative cognitions) than the TD group. At the same time, given that the former sample (AH) consists of adolescents with particularly blunted pleasure and interest, we predicted reduced mind-wandering to pleasant cognitive content (eg, anticipatory pleasure).[33,34] Second, we hypothesized that higher mind-wandering would be associated with higher concurrent and future (ie, time-lagged) negative affect (NA) and lower positive affect (PA). Finally, we expected that higher levels of mind-wandering would be associated with greater connectivity between the mPFC and other DMN nodes and SN nodes, as well as weaker connectivity between the mPFC and DAN nodes (and, given the literature reviewed above, that these relations may be

specific to the adolescents with elevated anhedonia and depressive symptoms). Analyses controlled for the related construct of rumination and examined the moderating influence of depression status.

METHOD

Participants

Adolescents (TD = 36, AH = 29) were recruited from the Greater Boston area. Participants were adolescents aged 12 to 18 years (both sexes) with English fluency. The following exclusion criteria were applicable to both groups: history of head trauma with loss of consciousness, history of seizure disorder, serious or unstable medical illness (eg, cardiovascular, hepatic, renal, respiratory, or hematologic disease), current use of cocaine, stimulant, or dopaminergic drugs, evidence of hypothyroidism, color blindness, and standard exclusion criteria for magnetic resonance imaging (MRI). For TD participants, additional exclusion criteria included a history of any *DSM-5* psychiatric or substance-related disorder, first-degree relative diagnosed with MDD, bipolar disorder, or a psychotic disorder, current use of any psychiatric medications, and a Snaith–Hamilton Pleasure Scale (SHAPS)[35] score of >0. As data for this study are derived from an ongoing trial for adolescents with anhedonia, the AH group were required to have elevated anhedonia on the basis of the SHAPS (total score $\geq$ 3, as assessed by the original scoring[35]) and Schedule for Affective Disorders and Schizophrenia for School-Age Children–Present and Lifetime Version (K-SADS-PL)[36] clinical interview (anhedonia item score >1). History or current diagnosis of any of the following *DSM-5* psychiatric illnesses were exclusionary for the AH group: schizophrenia spectrum or other psychotic disorder, bipolar disorder, anorexia nervosa or bulimia nervosa, substance (including alcohol) use disorder within the past 12 months or lifetime severe substance use disorder, or chronic depression (current episode $\geq$2 years). With the exception of obsessive-compulsive disorder (OCD), all anxiety disorders were permissible.

The study was approved by the Partners Healthcare Institutional Review Board. Assessments were completed over 2 days, and Ecological Momentary Assessment (EMA) data were collected during a 5-day span following the second session. During the initial session, participants completed a battery of self-report measures, including assessments of anhedonia and other depressive symptoms. The K-SADS for the *DSM-5* was subsequently administered. Participants completed a brief MRI simulation session (ie, "mock scan") at the end of the first session to familiarize themselves with the MRI procedure, in particular the confined space, the sounds of different pulse sequences (SimFx System), and the importance of minimizing any head motion (MoTrak software) (for evidence of the beneficial effects of mock scans, see, for example, de Bie *et al.*[37]). During the second session, participants underwent a 6-minute resting state functional MRI (fMRI) scan. The mean number of days between the first and second study sessions was 11.86 (SD = 6.95) for the TD group and 10.00 (SD = 6.51) for the AH group ($t_{63} = 1.10$, $p = .43$). Following the second session, participants were sent 2–3 ecological momentary assessment (EMA) surveys a day for 5 days (Thursday through Monday) using the Metricwire app that they downloaded on their iPhones or Android phones (for additional details, see Supplement 1, available online; and for similar EMA designs in adolescents, see Forbes *et al.*[38,39]). See Table S1, available online, for clinical and demographic characteristics of the AH and TD samples.

Measures

Schedule for Affective Disorders and Schizophrenia for School-Age Children. The Schedule for Affective Disorders and Schizophrenia for School-Age Children (K-SADS-PL)[36] is a semi-structured clinical interview that assesses for current and past psychiatric disorders according to the *DSM-5*. Research assistants who were bachelor's degree level conducted the interviews under the supervision of the first author, after receiving at least 40 hours of training.

Snaith–Hamilton Pleasure Scale. The Snaith–Hamilton Pleasure Scale (SHAPS)[35] is a 14-item self-report measure that assesses anhedonia within several domains (eg, "I would find pleasure in my hobbies and past-times"). Participants rated the extent to which they agreed with each statement on a 4-point scale ranging from 1 (strongly agree) to 4 (strongly disagree). Following prior recommendations, a dimensional scoring was used (possible range, 14–56), with a higher score indicating a higher level of anhedonia.[40]

Center for Epidemiologic Studies Depression Scale. The Center for Epidemiologic Studies Depression Scale (CES-D)[41] is a 20-item self-report measure that examines depressive symptom severity over the past week. This measure includes a 4-point scale ranging from 0 (rarely or none of the time to <1 day) to 3 (most or all of the time to 5–7 days). A higher score indicates a higher severity of depressive symptoms, with four items being reversed scored.

EMA Measures

Positive and Negative Affect. Similar to previous EMA studies in adolescents, participants completed a subset of items from the Positive and Negative Affect Schedule for Children (PANAS-C) at each survey timepoint.[38,39]

Participants were instructed to respond based on how they were feeling immediately before receiving the survey on a 5-point scale ranging from 1 (very slightly or not at all) to 5 (extremely). Ratings for three positive emotions (happy, interested, and excited) and three negative emotions (sad, nervous, and angry) were averaged to created indices of PA and NA, respectively.

Mind-Wandering. At each timepoint, thought-probes inquired about what participants were thinking about immediately prior to the survey. As in Killingsworth and Gilbert,[3] they were asked "Were you thinking about something other than what you were doing?" In addition, and in contrast to the latter study, participants were also asked whether they were thinking about something in the future, past, or neither. Endorsement of thoughts about the past or future were coded as mind-wandering (even if the participant response was "no" to the above mind-wandering question). Moreover, participants who were mind-wandering were asked whether they were thinking about something pleasant, unpleasant, or neutral. For a note on alternative definitions of mind-wandering, see Supplement 1, available online.

Current Activity. Participants reported the activity that they were engaged in at the time of receiving the survey. Activities were coded by a research assistant into categories from Killingsworth and Gilbert,[3] but were adapted for adolescents (eg, school-related activities, such as homework). For details, see Supplement 1, available online.

Social Context. Participants were asked if they were with anyone at the time of the survey and, if so, whom. Responses were coded by research assistants into the following categories: family, friend(s), significant other, other, or no one.

Rumination. Participants were asked to consider the most stressful time since they completed the last survey. Similar to Ruscio *et al.*,[8] participants were then asked to rate the following 2 rumination items on a 5-point scale (1 = very slightly or not at all to 5 = extremely): "After this stressful thing happened, I was dwelling on my mistakes, failures, or losses" and "After this stressful thing, I kept thinking about something negative that happened." The average of these 2 items was used as our measure of rumination, which has been previously shown to correlate robustly (both $r = .57$) with 2 well-validated self-report rumination questionnaires: the Ruminative Responses Scale, and the Rumination scale of the Rumination−Reflection Questionnaire.[8]

Magnetic Resonance Image Acquisition

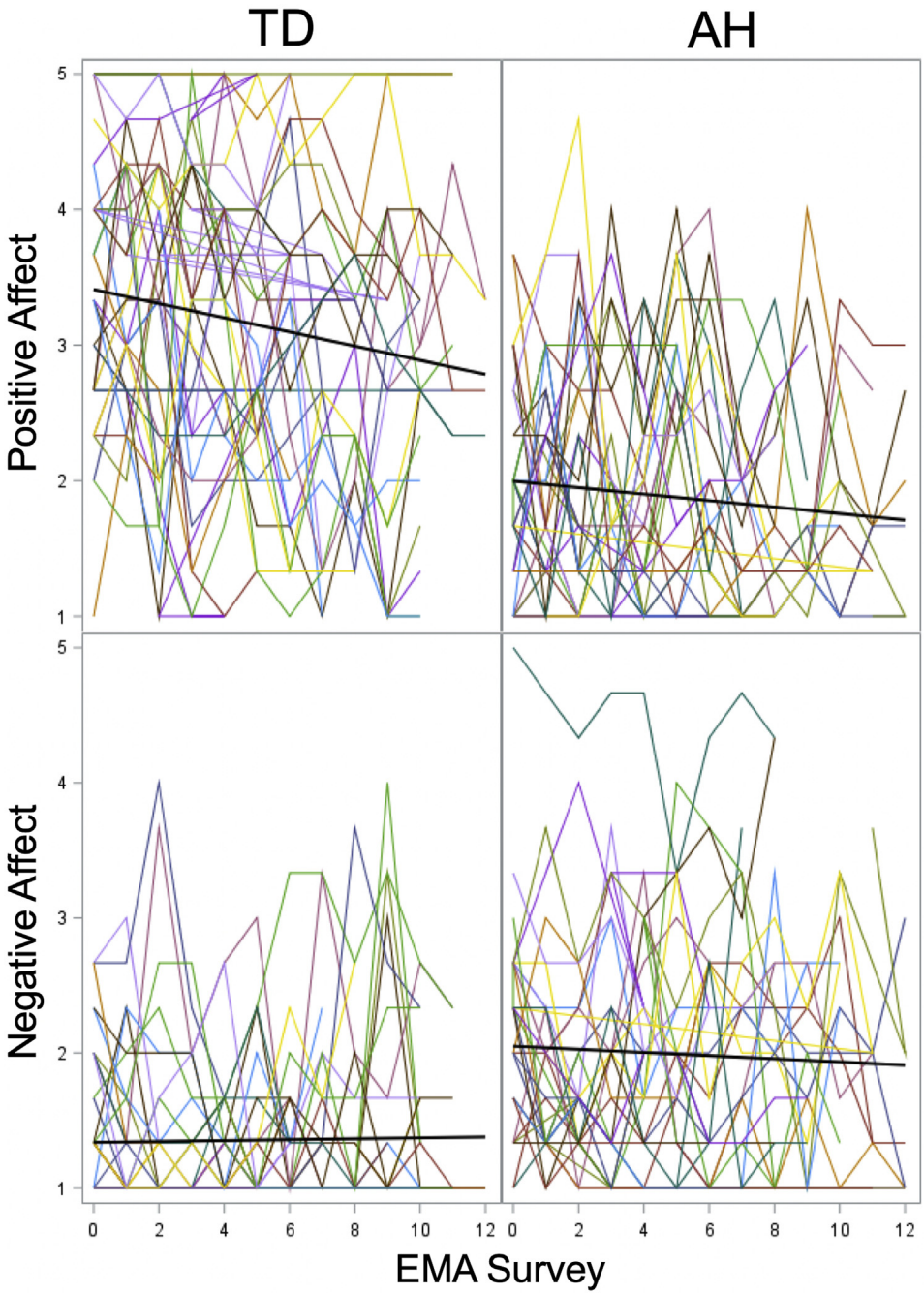
All participants completed a T1-weighted structural scan and a 6-minute 51-second resting state fMRI scan. During the resting state scan, participants viewed a black screen and were instructed to keep their eyes open. Eighteen participants completed their scan on a Siemen's Tim Trio 3.0 Tesla MRI system equipped with a 32-channel coil, and the remaining participants completed their scan on a Siemen's Prisma 3.0 Tesla MRI system equipped with a 64-channel coil at McLean Hospital. Identical resting state and structural scan parameters were used at both MRI scanners. There were no significant differences between participants scanned on the Prisma or Trio with regard to age, sex, depression, anhedonia, mind-wandering, or percentage of resting state data volumes removed (see Supplement 1, available online), and scanner type was included as a covariate in the functional connectivity analyses. For imaging acquisition details, see Supplement 1, available online.

Analytic Approach

EMA Analyses. We used a multilevel modeling (MLM) approach to analyze these data. Specifically, for analyses with continuous dependent variables (ie, NA and PA), and due to the nested (hierarchical) data structure (ie, EMA assessments nested within individuals, who are in turn nested within groups), we used SAS (version 9.4) mixed procedure (PROC MIXED) with maximum likelihood estimation, and specifying a random intercept and slope. To test the association between predictor variables (eg, mind-wandering) and affect over time, a vector of PA or NA (depending on the analysis) scores for each participant served as the dependent variable (time T), with scores on the given predictor variable entered as the independent variable (also at time T). For lagged analyses, predictor variables (eg, mind-wandering) at time T were used to predict the dependent variable (eg, NA or PA) at the next EMA timepoint (ie, time T + 1), with scores on the dependent variable at the previous session (time T) entered as a covariate. PROC GLIMMIX was implemented for binary or multinomial dependent variables. Hedges g effect sizes are reported, using Cohen guidelines for small (<0.2), moderate (0.5), and large (>0.8) effects.[42]

fMRI Analysis. The mPFC seed region of interest (ROI) was gray matter masked and incorporated voxels falling within the DMN. The time series from the mPFC seed was correlated with the time series from other regions encompassing the DMN: specifically, the posterior cingulate cortex (XYZ coordinates: 1, −61,38) and the lateral parietal cortex (left: −39, −77,33, right: 47, −67,29); the SN: the anterior insula (left: −44,13,1, right: 47,14,0), rostral prefrontal

FIGURE 1 Plot Displaying Variability in Positive Affect (PA) and Negative Affect (NA) for Typically Developing (TD) Control (Left Panel) and Participants With Anhedonia (AH) (Right Panel)



Note: *Each colored line represents PA or NA scores for one participant over the 5-day ecological momentary assessment (EMA) collection period. The black line represents the regression line. Please note color figures are available online.*

cortex (left: −32,45,27, right: 32,46,27), supramarginal gyrus (left: −32,45,27, right: 62, −35,32), and the ACC (0,22,35); and the DAN: frontal eye fields (left: −27, −9, 64, right: 30, −6,64), and intraparietal sulcus (left: −39, −43,52, right: 39, −42,54). These ROIs were defined from CONN's Independent Component Analysis analysis of 497 participants from the Human Connectome Project dataset. The mPFC-to-ROI correlation maps were normalized using a Fisher Z transformation and were used to calculate all group-level statistics. All fMRI analyses were corrected for multiple comparisons using a false discovery rate (FDR) of $p < .05$ (14 target ROIs). Multiple linear

TABLE 1 Relation Between Mind-Wandering and Negative/Positive Affect

Predictor	Dependent variable	F	p
Group (AH/TD)	NA	28.90	<.001
Activity		1.09	.363
Social companion		0.40	.809
Day of week (sunday/friday)		5.04	.002
Mind-wandering (yes/no)		15.24	<.001
Group (AH/TD)	PA	45.30	<.001
Activity		1.27	.225
Social companion (other/so)		8.46	<.001
Day of week (sunday/friday)		3.16	.027
Mind-wandering		3.31	.074

Note: For significant variables, terms in parentheses represent the level of that variable associated with worse affect (to the left of the slash mark [/]) and best affect (to the right of the slash mark [/]). For example, for day of week, negative affect (NA) was highest and positive affect (PA) was lowest on Sundays. Conversely, NA was lowest and PA was highest on Fridays. Models control for time (ie, ecological momentary assessment [EMA] survey number), and include a random intercept and slope. AH = elevated anhedonia group; SO = significant other; TD = typically developing controls.

regression analyses were conducted to examine associations between mPFC-target network ROIs RSFC and mind-wandering while controlling for age, sex, and scanner (Trio versus Prisma). For details on fMRI processing, see Supplement 1, available online.

RESULTS

Between-Group, Between-Individual, and Within-Individual Variability in Affect

Relative to the TD group, participants with AH reported significantly lower PA (3.15 ± 0.91 versus 1.89 ± 0.54; $t_{63} = 7.23$, $p < .001$; Hedges's $g = 1.64$) and higher NA (1.36 ± 0.41 versus 2.02 ± 0.69; $t_{63} = -5.04$, $p < .001$; $g = 1.20$) on EMA surveys. For the TD group, intraclass correlation coefficients were 0.60 and 0.43 for PA and NA, respectively, indicating that approximately half (40%–57%) of the variance in affect was due to variability within individuals over time (Figure 1, left panel). For the AH group, the corresponding intraclass correlation coefficients were 0.32 and 0.55, indicating that 68% of the variance in PA and 45% of the variance in NA was within-person variability (Figure 1, right panel). In sum, there was substantial within-individual variability in affect over time in both groups, which we modeled below.

Frequency and Content of Mind-Wandering

The frequency of mind-wandering was higher for participants with AH (70.0% of EMA samples) relative to TD (59.2% of samples) participants ($F_{1,63} = 4.60$, $p = .036$). In addition, a multinomial logistic regression indicated that there was a significant between-group difference in the content (pleasant, unpleasant versus neutral thoughts) of mind-wandering ($F_{2,128} = 6.77$, $p = .002$). Specifically, participants with AH were more likely to mind-wander to unpleasant content (41.5%), relative to pleasant (27.4%) or neutral (31.1%) content, whereas TD participants were more likely to mind-wander to pleasant content (47.3%) (unpleasant, 20.3%; neutral, 32.4%).

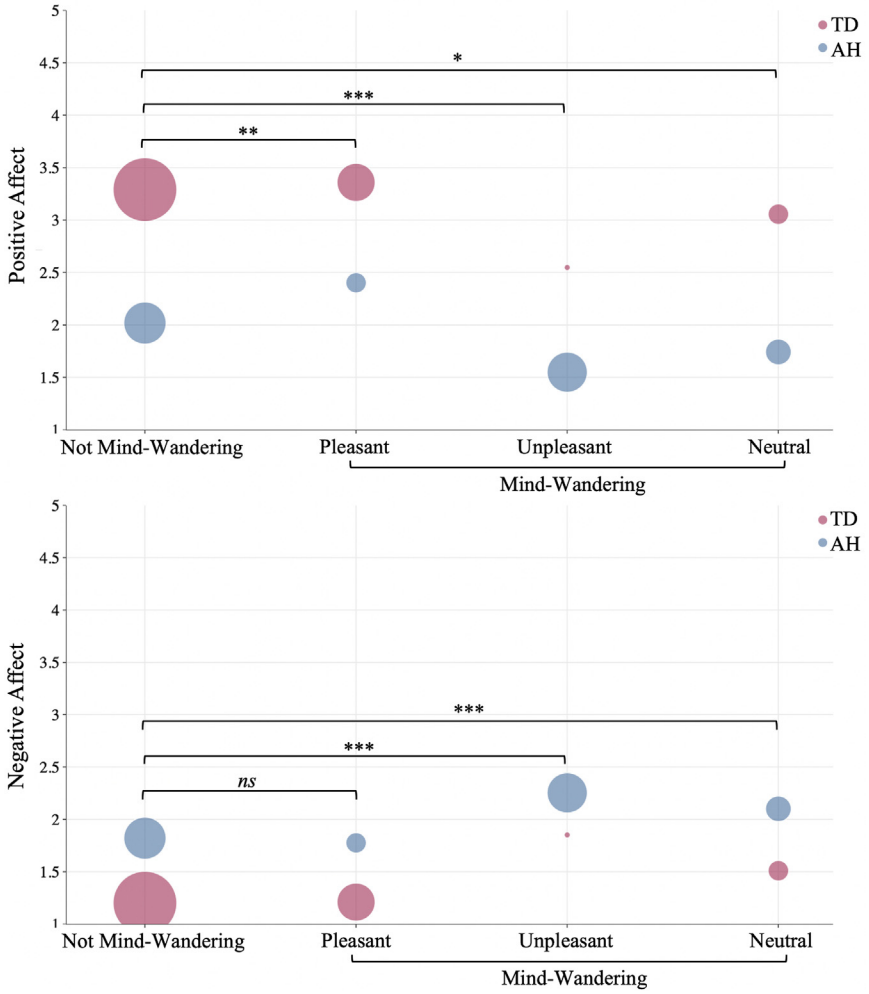
Mind-Wandering and Variability in Affect

Group by mind-wandering interaction terms were not significant in predicting either NA ($F_{1,56} = 0.00$, $p = .995$) or PA ($F_{1,56} = 0.02$, $p = .880$), and thus analyses were collapsed across groups. Importantly, mind-wandering was associated with higher NA ($F_{1,57} = 15.24$, $p < .001$), even when controlling for current activity, social companion, day of the week, and group (AH or TD) (Table 1, upper portion; even when analyses were run for each group separately, mind-wandering was associated with higher NA (AH, $p = .007$; TD, $p = .012$), controlling for current activity, social companion, and day of the week). A parallel analysis predicting PA yielded a nonsignificant trend ($F_{1,57} = 3.31$, $p = .074$) (Table 1, lower portion). Given the overlap between the constructs of mind-wandering and rumination, the significant NA analyses was re-run adding rumination as an additional covariate. Mind-wandering remained significantly associated with higher NA ($F_{1,56} = 11.82$, $p = .001$). Moreover, the association between mind-wandering and higher NA also remained significant if controlling for depressive (CES-D) and anhedonic (SHAPS) symptom severity ($F_{1,57} = 14.93$, $p < .001$), and neither variable moderated the relation between mind-wandering and NA (ie, mind-wandering by CES-D and mind-wandering by SHAPS interactions $p > .765$).

Consideration of the Valence of Mind-Wandering

The above analyses used a binary coding of mind-wandering (ie, mind-wandering versus not). To examine the relation between the valence of mind-wandering and affect, mind-wandering was re-coded as follows: mind-wandering to pleasant, unpleasant, or neutral content; and not mind-wandering. The latter mind-wandering variable was robustly associated with both NA ($F_{3,136} = 13.03$; $p < .001$) and PA ($F_{3,136} = 16.12$; $p < .001$) (Figure 2), even when controlling for current activity, social companion, day of the week, group, and rumination (Table 2). Specifically, model-derived least-squares means revealed that NA was lowest when not mind-wandering (1.55) and highest when mind-wandering to negative content (1.90). PA was highest when mind-wandering to pleasant content (2.80) and

FIGURE 2 Mean Positive Affect (PA) (Top Panel) and Negative Affect (NA) (Bottom Panel) for Typically Developing (TD) Control (Pink) and Participants With Anhedonia (AH) (Blue) While Not Mind-Wandering Versus Mind-Wandering to Pleasant, Unpleasant, or Neutral Topics



Note: *Bubble area is proportional to the frequency of ecological momentary assessment (EMA) samples for that group. For example, the largest bubble (TD not mind-wandering) corresponds to 40.8% of the samples, and the smallest bubble (TD) mind-wandering to unpleasant topic) corresponds to 12% of the samples. Significance markers (*) reflect p values for tests of differences in PA or NA between not mind-wandering and each mind-wandering category.*
*p < .05; **p < .01; ***p < .001.

lowest when mind-wandering to unpleasant content (2.18). Finally, time-lagged analyses showed a bidirectional association between the latter mind-wandering variable and PA. Specifically, mind-wandering predicted future PA ($F_{3,134} = 2.93$; $p = .036$), with mind-wandering to unpleasant content predicting the lowest PA at the next EMA timepoint. Conversely, lower PA predicted an increased likelihood of mind-wandering to unpleasant content at the next EMA timepoint ($\beta = -0.37$; $p = .014$). Corresponding analyses with NA were not significant (p values >0.33).

Functional Connectivity

A group by mind-wandering interaction was not significant. However, secondary analyses by group were conducted to test a priori hypotheses. Within the AH group, higher levels of mind wandering were associated with stronger RSFC between the mPFC and multiple nodes of the SN (bilateral anterior insula and bilateral rostral prefrontal cortex) as well as the DAN (left frontal eye field and right intraparietal sulcus) (Figure 3). Each of these associations remained significant when adding PA, NA, and rumination as additional covariates, with the exception of the mPFC–left rostral prefrontal cortex and mPFC–left frontal eye field relations (both $p = .06$, FDR corrected for 14 target ROIs). No significant associations emerged in the TD group. In response to an anonymous reviewer, functional connectivity data were reprocessed using global signal regression, and 4/6 ROI-ROI effects remained significant (see Supplement 1, available online).

TABLE 2 Relation Between Mind-Wandering (With Valence Categories) and Negative/Positive Affect

Predictor	Dependent variable	*F*	*p*
Group (AH/TD)	Negative Affect	14.66	<.001
Activity		1.22	.260
Social companion		0.34	.847
Day of week (sunday/friday)		3.61	.015
Rumination		33.48	<.001
Mind-wandering (unp. MW/not MW)		13.03	<.001
Group (AH/TD)	Positive affect	37.21	<.001
Activity		1.61	.071
Social companion (other/so)		8.75	<.001
Day of week		2.37	.073
Rumination		1.35	.247
Mind-wandering (unp. MW/pl. MW)		16.12	<.001

Note: For significant variables, words in parentheses represent the level of that variable associated with worse affect (to the left of the slash mark [/]) and best affect (to the right of the slash mark [/]). For example, for Day of Week, NA was highest on Sundays and lowest on Fridays. Models control for time (ie, ecological momentary assessment [EMA] survey number), and include a random intercept and slope. AH = elevated anhedonia group; Not MW = not mind-wandering; Pl. MW = mind-wandering to pleasant content; TD = typically developing controls; Unp MW = mind-wandering to unpleasant content.

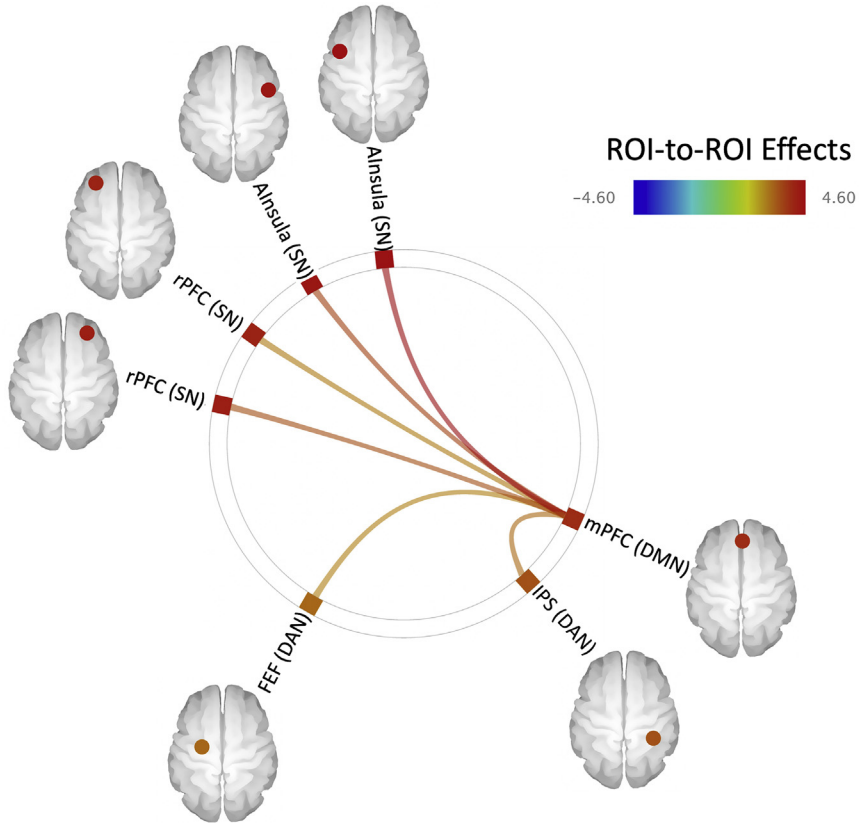
DISCUSSION

Mind-wandering was highly frequent in the TD (59.2% of samples) and AH (70.0% of samples) adolescents. Across both groups, participants reported higher NA when mind-wandering than when focused on their current activity. Importantly, this association was significant when controlling for current activity, social companion, and day of the week. The highly cited Killingsworth and Gilbert study also reported that mind-wandering was associated with lower levels of happiness. However, given that the latter study recruited an unselected sample, it is unknown to what extent findings were influenced by depression. Specifically, to the extent that depression predicts both worse mood and higher levels of mind-wandering (eg, due to elevated rumination), it would represent a third variable confound. In the present study, rumination was associated with both higher NA ($r = 0.49$; $p < .001$) and mind-wandering ($r = 0.16$; $p < .001$) in the full sample. However, the relation between mind-wandering and higher NA remained significant when controlling for rumination. Of course, there may be other reasons, beyond rumination, why individuals with depression report higher levels of mind-wandering (eg, because of attentional control deficits) and worse affect, yet mind-wandering per se may not cause worse affect. In other words, depression may remain a third variable confound even when controlling for rumination. In the present study, the relation between mind-wandering and NA remained significant when controlling for depression, either as a continuous (CES-D) or categorical (TD or AH) variable.

Next, we considered the content of mind-wandering. As displayed in Figure 2, it is important to note that participants reported both lower PA and higher NA when mind-wandering to unpleasant content and even neutral content than when focused on their present activity (ie, not mind-wandering). Moreover, even when mind-wandering to pleasant content, NA was not significantly lower relative to when not mind-wandering (although a significant difference did emerge for PA). It is also noteworthy that despite differences between groups in mean levels of PA and NA, as well as between-group differences in the prevalence of different categories of mind-wandering (eg, mind-wandering to unpleasant content: TD, 12% of surveys; AH, 29% of surveys), the affective correlates of mind-wandering were strikingly similar within each group. Namely, as seen in Figure 2, for both TD participants and participants with AH, PA was highest when mind-wandering to pleasant content, followed by not mind-wandering, mind-wandering to neutral content, and, finally, lowest when mind-wandering to unpleasant content (with a similar pattern of between-group consistency for NA).

Given that analyses based on concurrent assessments of affect and cognition cannot address causal direction, time-lagged analyses were conducted to test whether mind-wandering predicted future affect (ie, at the next EMA timepoint), and vice versa. These analyses suggested a bidirectional association between mind-wandering and PA (but not NA). Although such time-lagged analyses are important to rule out temporal confounds inherent in testing concurrent associations, they are not without their limitations. EMA does allow for a relatively dense assessment of affect and cognition (eg, several times per day). However, the time course of the causal relation between changes in cognition and affect may be too brief (eg, on the order of milliseconds to seconds) to be captured by EMA assessments spaced several hours apart, on average. Although future studies could deploy EMA surveys more frequently, it is important to be mindful of not overburdening participants, which may negatively influence survey compliance and the validity of responses (eg, encouraging random or stereotyped responding to items). Rather than relying on observational designs to test the causal relation between mind-wandering and affect, participants could be randomly assigned to an experimental manipulation of mind-wandering to test its effect on affect.

FIGURE 3 Correlations Between Mind-Wandering and Medial Prefrontal Cortex (mPFC) Seed With Other Regions of the Default Mode Network (DMN), Salience Network (SN), and Dorsal Attention Network (DAN)



Note: Analyses were corrected for multiple comparisons using a false discovery rate of p < .05 (14 target regions of interest [ROIs]). Significant associations within anhedonia (AH) group are displayed. Please note color figures are available online.

Of relevance, several studies have shown that mindfulness training reduces mind-wandering, assessed via subjective self-report and objective (eg, sustained attention to response task [SART]) measures.[43,44] However, it is unknown whether reductions in mind-wandering result in increased PA and/or decreased NA.

Several notable functional connectivity findings emerged between the mPFC—a core hub of the DMN linked to self-referential processing and internal mentation—and nodes of the SN and DAN. The DMN has commonly been linked to off-task cognition and mind-wandering.[10] However, functional connectivity within the DMN (ie, between the mPFC and other nodes of the DMN) was not significantly related to mind-wandering. Instead, higher levels of mind-wandering within the AH group were associated with stronger connectivity between the mPFC and several nodes of the SN and DAN. The SN has been implicated in the detection and filtering of salient information and toggling between internally oriented attention (DMN) and externally oriented attention (DAN). The link between mind-wandering and enhanced mPFC-SN coupling may reflect heightened bottom-up influence of affective and sensory salience on DMN-mediated internally oriented thought.[10] In other words, affective and sensory stimuli may be more likely to capture and draw attention inward for individuals with enhanced mPFC-SN connectivity, triggering episodes of mind-wandering. Of relevance, one recent study assessed mind-wandering during a choice reaction time task and observed that adolescents with maltreatment history had significantly fewer positively valenced spontaneous thoughts and reduced functional connectivity between the subgenual ACC and frontoparietal network.[45] Mindfulness training, with its emphasis on the development of meta-cognitive awareness and attentional control, may be a useful intervention to reduce mind-wandering.[43,46] Specifically, adolescents with low mood due, at least in part, to excessive mind-wandering may benefit from systematic training in attentional control and metacognitive skills via mindfulness-based techniques (eg, focused attention and/or open monitoring meditation practices)[44] and learning to catch episodes of

mind-wandering as they occur. Neurofeedback may also provide a promising avenue for modulating mind-wandering and attentional control.[47] Finally, intervention studies may benefit from tracking, via EMA, mind-wandering to positive content.

Several limitations of the present study should be noted. First, more frequent daily surveys, and for a period longer than 5 days, would provide more power and temporal resolution to disentangle the relation between cognition and affect. Second, as noted above, it is important to highlight that mind-wandering is a highly heterogeneous cognitive construct. This study focused on one dimension of mind-wandering (ie, valence of its content). Other unexamined dimensions of mind-wandering (eg, whether intentional or unintentional) may moderate its effect on affect. Importantly, other beneficial outcomes of mind-wandering (eg, fostering creative thinking) were not the focus of the present study.[10] Third, nonsignificant interactions may have been due, at least in part, to low power from our relatively small sample size. Fourth, two scanners were used (scanner type was included as a covariate). Fifth, given that a dimensional measure of attention-deficit/hyperactivity disorder (ADHD) symptoms was not included, it is unclear to what extent these symptoms may influence mind-wandering findings (although only one participant met diagnostic criteria for ADHD, as stimulant use was exclusionary). These limitations notwithstanding, the present findings suggest that, overall, mind-wandering in adolescents may contribute to worse affect and, among those characterized by anhedonia, is related to aberrant functional connectivity between brain regions linked to self-referential processing and internal mentation, salience detection, and externally oriented attention.

Accepted June 8, 2020.

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This work was supported by a grant from the National Institute of Mental Health (NIMH; K23 MH108752; Dr. Webb) and the Klingenstein Third Generation Foundation (Dr. Webb). The content is solely the responsibility of the authors and does not necessarily represent the official views of the funding agencies.

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Disclosure: Dr. Webb has received research support from NIMH, the Brain and Behavior Research Foundation and the Tommy Fuss Fund. Dr. Belleau has received grant support from the Klingenstein Third Generation Foundation. Dr. Forbes has received research support from the National Institutes of Health, consulting fees from a trial funded by Durham, NC VA, sponsorship by Otsuka Pharmaceuticals, and honoraria from the Association for Psychological Science and Brown University Alpert Medical Center (unrelated to the current project). Dr. Pizzagalli has received consulting fees from BlackThorn Therapeutics, Boehringer Ingelheim, Compass Pathways, Otsuka Pharmaceuticals, and Takeda Pharmaceuticals, as well as an honorarium from Alkermes for activities unrelated to the current project. In addition, he has received stock options from BlackThorn Therapeutics and research support from NIMH (R37 MH068376), the Dana Foundation, the Brain and Behavior Research Foundation, and Millennium Pharmaceuticals. Mss. Israel and Appleman have reported no biomedical financial interests or potential conflicts of interest.

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https://doi.org/10.1016/j.jaac.2020.03.010

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