**Adolescent Emotion Network Dynamics in Daily Life and Implications for
Depression**

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Acknowledgments

This study was supported by the Karl R. and Diane Wendle Fink Early Career Professorship for the Study of Families, the National Institute on Drug Abuse (NIDA T32 DA017629; P50 DA039838), an ISSBD-JJF Mentored Fellowship, and the Penn State Social Science Research Institute. The content is solely the responsibility of the authors and does not necessarily represent the official views of the funding agencies. We gratefully acknowledge the contributions of Keiana Mayfield, Emily LoBraico, Amanda Ramos, and Devin Malloy for their assistance in collecting and preparing the data, and to the participating schools and families that made this project possible.

For the most recent version of this manuscript, see the published version at *Journal of Abnormal Child Psychology*, doi: 10.1007/s10802-018-0474-y

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Abstract

Objective. Emotion network density describes the degree of interdependence among emotion states across time, such that higher density reflects self-perpetuating emotions or rigidity in emotion functioning. Higher density in emotion networks appears to be a risk factor for depression in studies of adults. This paper extended research on emotion network density to adolescents and examined: 1) associations between emotion network density and a standard measure of emotion regulation and 2) associations between emotion network density and symptoms of depression. **Method.** Data from a daily diary study ($t=21$ days) of adolescents ($N=151$; 61.59% female; *mean age*=14.60 years) were used to construct emotion network density scores. Emotion regulation was measured using The Difficulties in Emotion Regulation Scale Short Form (DERS-SF). Associations between emotion network density and DERS-SF were examined through Pearson correlations. Multiple regression analyses examined associations between emotion network density and depression. **Results.** Emotion network density was not associated with the DERS-SF. Follow-up analyses showed that it was associated with non-acceptance of emotions (a subscale of the DERS-SF). Emotion network density was positively associated with depression. **Discussion.** Non-acceptance of emotions may encourage the spread of emotion across time and emotion states given that a feature of non-acceptance is to have secondary emotional responses to one's emotions. Rigidity in emotion function in the form of context-insensitive, self-perpetuating emotion networks may be a risk factor for adolescent depression.

Keywords: Emotion network density, intensive repeated measures, emotion regulation, adolescence, depression

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Emotional disturbances are a prevalent feature in models of psychopathology (Cicchetti et al., 1995; Mennin & Farach, 2007) and difficulties in the ability to regulate emotions appropriately predict numerous forms of psychopathology (Aldao et al., 2010). Depression and anxiety disorders, for example, have as core symptoms excessive levels of sadness and anxiety, respectively (American Psychiatric Association, 2013). However, models of psychopathology do not only focus on higher average levels of negative affect. Indeed, emotions and their regulation are dynamic processes (e.g., Gross, 2015; Kuppens & Verduyn, 2015); how emotions unfold during daily life, moment-to-moment, also play an important role in understanding psychopathology risk (Csikszentmihalyi & Larson, 2014; Trull et al., 2015). The purpose of the present study was to investigate individual differences in emotion network dynamics in day-to-day life and their association with symptoms of depression during adolescence.

Rigidity in Emotions and Psychopathology

Emotions have multiple aspects – the subjective experience of emotional events, emotion behaviors, and emotion physiology – that all work to motivate and organize responses to stimuli and situations, but they may serve different functions (Cicchetti et al., 1995; Gross, & Munoz, 1995). For example, the physiological states that accompany emotions prepare organisms to act in certain ways while associated behavioral expressions serve communicative functions (Campos et al., 1989). While emotions alert us to important changes in our environments and facilitate responding to these changes (Kashdan & Rottenberg, 2010; Izard, 2009), their influence on behavior may be

modulated. In other words, "people not only have emotions, they also handle them" (Frijda, 1986, p. 401). The modulation of emotion is a necessary process, enabling optimal engagement in situations or responding to stimuli (Cole et al., 2004). Emotional reactions often reflect the up-regulation of emotions to motivate engagement to enact change or respond to a situation or stimulus, but must be balanced with adequate down-regulation to ensure appropriate responses that can avoid undesirable consequences for the well-being of the individual and/or those around the individual (Berenbaum, 2003). Emotion regulation research highlights processes that modulate the occurrence, intensity, and duration of emotional experiences (Cicchetti et al., 1995; Cole et al., 2004; Thompson, 1990). Emotion regulation is thought to be adaptive when emotions persist until goals are achieved but respond flexibly (e.g., rise and fall when appropriate) to accommodate changing environmental demands (Thompson, 1994).

Flexibility or rigidity in emotional responding also is an important feature in understanding how emotion regulation serves as a key underlying factor in psychopathology. Individuals capable of managing their experiences and their expressions of emotion in a context-sensitive manner appear most able to respond to life's demands (Menin et al., 2007). Emotion regulation processes are less successfully deployed in psychopathology (Aldao et al., 2010; Sheppes et al., 2015). Emotions in psychopathology are characterized by rigidity rather than flexibility, manifesting as a contextually inappropriate persistence in emotions across time despite changes in contexts, goals, and demands (Hollenstein et al., 2013; Houben et al., 2015). Without the flexibility (rigidity's counterpart) in emotion that is important for promoting an adaptive

interplay between the individual and changing environmental demands, there may be undesirable consequences for the well-being of the individual.

A Network Perspective on Emotion Processes

To capture within-person variability in emotions, many have turned to experience-sampling methods, in which individuals are repeatedly measured as they go about their daily lives (Bolger et al., 2003; Larson & Csikszentmihalyi, 1983; Shiffman et al., 2008). The repeated assessment of individuals allows researchers to capture moment-to-moment fluctuations in emotion (Ram & Gerstorf, 2009). In this dynamic perspective of emotions, emotional rigidity is manifest as the extent to which individuals persevere in an emotional state from moment to moment, or day to day. This has been described in terms of emotion inertia, an index of the temporal dependency of a time series (Jahng et al., 2008). Higher inertia values signify greater perseveration in an emotion state over time and indicate a decoupling of emotions from their adaptive functions (Kuppens et al., 2010). Rather than responding flexibly in a context-sensitive manner, emotions with high inertia values respond to themselves in a rigid, self-perpetuating manner. Consistent with theory, both laboratory and experience-sampling paradigms have observed a positive association between greater emotion inertia (rigidity) and depressive symptoms (Brose et al., 2015; Koval et al., 2013). These findings demonstrate the value of the dynamic perspective of emotions for testing theories of the role of emotion rigidity in risk for psychopathology.

Novel insights into emotion dynamics and their associations with symptoms of psychopathology have recently been gained by considering dynamics *between* as well as *within* emotion states across time. This *emotion network* perspective, in which

connections between emotion states are considered, extends inertia's focus on rigidity in one emotion state by allowing for the possibility that one's current emotion state may give rise to other emotions. For example, one may feel embarrassment over an angry outburst. This possibility has long been emphasized in emotion theory (e.g., Gross & Munoz, 1995) and there is also empirical support for the moment-to-moment transfer of emotions across time and states (Anand et al., 2016; Fredrickson & Joiner, 2002; Pe & Kuppens, 2012).

Some degree of emotion transfer across time and states is normative. However, just as inertia has been viewed as rigidity in emotion functioning at the level of individual emotions, network density – an indication of the strength of the temporal connections within and between emotions – can be conceived of as rigidity at the network level. Substantial spread of emotions across time and states (operationalized as high network density values) manifests in the form of a self-perpetuating network of interdependent states, suggestive of an emotion system that is self-predictive (Kuppens & Verduyn, 2015). In a self-predictive emotion system, emotions respond to themselves rather than to ongoing events of potential importance, undermining the context-sensitive flexibility that characterizes healthy and adaptive emotional functioning. For example, in the case of a stressor-induced increase in sadness, an individual with an emotion network with relatively strong connections between sadness and anger may be likely to experience anger following the experience of sadness. In an individual with weaker connections between sadness and anger, the impact of the stressor on the emotion network may die out much more quickly (Wichers, 2014).

Preliminary Evidence Linking Network Density and Psychopathology in Adults

Support for the network perspective of emotions in psychopathology has emerged in a number of studies of adults. These studies applying network methods offer support for the notion that a denser (e.g., self-perpetuating) network is a risk factor for psychopathology. One study by Wigman and colleagues (2015) examined “mental state” networks (comprised of: cheerful, content, down, insecure, and suspicious mental states). Their findings indicated that individuals with depression tended to have denser, more self-perpetuating mental state networks, providing evidence that negative mental states reinforced each other and also reduced positive states in the depressed group. In a similar study examining connections across negative affect, positive affect, and paranoia in women, denser connections across time were observed with greater symptom severity measured by the Symptom Checklist-90-R (Wigman et al., 2013). Other work has focused specifically on emotion networks and examined connections among affect items exclusively. Pe and colleagues (2015) compared emotion networks for 53 adults with major depression and 53 control adults (defined as individuals who experienced no current or past mental-health disorders and with a score of 9 or less on the Beck Depression Inventory-II). Emotion network density was higher in adults with major depressive disorder than in comparison adults, again highlighting that an underlying process in psychopathology, and especially depression, is a rigidity of emotion states characterized by a lack of context-sensitivity, with emotions self-perpetuating, rather than responding flexibly to the environment (e.g., Koval et al., 2013; Kuppens et al., 2010).

The Present Study: Emotion Network Density and Adolescent Depression

At this time, the literature awaits the application of emotion network processes to adolescent developmental risk for depression. Adolescence is a time of normative increases in the prevalence of mood disorders, particularly depression and anxiety (Beesdo et al., 2009; Birmaher et al., 1996; Kessler et al., 2001). Interestingly, emotion dynamics may be particularly salient during adolescence. For example, adolescents tend to report a greater range of emotion (Larson et al., 1980) and exhibit more extreme mood swings (e.g., Maciejewski et al., 2015) relative to adults. These normative differences between adolescents and adults may stem from adolescence being a time of increased exposure to stressors (Larson & Ham, 1993), increases in the intensity of parent-child conflict (Laursen et al., 1998), and a time during which emotion regulation capacities are still developing (Casey et al., 2008; Zimmermann & Iwanski, 2014). Thus, applying dynamic methods to the study of adolescent emotion processes may offer fruitful new inroads to understanding psychopathology risk.

The limited research of emotion dynamics in adolescents supports the view that rigidity is a key risk factor for psychopathology. Kuppens and colleagues (2010) compared inertia in angry, happy, and dysphoric behaviors (at intervals of 5 seconds) during family interaction tasks in 72 depressed and 64 non-depressed adolescents. Greater emotion inertia was observed in depressed relative to control participants. In terms of the predictive nature of emotion inertia for the emergence of clinical depression, greater inertia in both negative and positive emotional behaviors during videotaped interactions with a parent predicted the emergence of clinical depression 2.5 years later in a sample of 165 early adolescents (Kuppens et al., 2012). These findings suggest that

rigidity in emotions as captured by emotion inertia is characteristic of psychopathology during adolescence as well as adulthood and acts as a risk factor for subsequent psychopathology. The extent to which psychopathology during adolescence is characterized by rigidity in emotion network functioning is unclear.

The Present Study

In this study, we sought to examine adolescent emotion networks in the service of two major aims. The first aim was to begin the task of examining the processes associated with individual differences in emotion network density. Previous studies have speculated that emotion network density may partially result from difficulties in emotion regulation (Pe et al., 2015), with emotions becoming unresponsive to efforts to modulate the emotion system. To explore this possibility, we examined associations between emotion network density and a widely used measure of emotion regulation difficulties. We hypothesized that emotion network density would be positively associated with difficulties in emotion regulation. The second aim was to evaluate whether emotion network density was associated with symptoms of depression. Guided by recent work in the adult literature (Pe et al., 2015), we hypothesized that denser emotion networks would be associated with greater symptoms of depression. By considering the association between emotion network density and a measure of emotion regulation, the added value of emotion network density in understanding adolescent depression above and beyond standard measures of emotion dysregulation was examined.

METHOD

The present study made use of data from The Family Life Optimizing Well-being (FLOW) study, an intensive longitudinal study designed for the study of day-to-day

intraindividual variability across a range of domains of functioning in parents and their adolescent children, including emotions, family functioning, and well-being.

Participants

Participants were 151 families of 9th and 10th grade adolescents recruited through high schools in Pennsylvania. Families were eligible for participation if they met six criteria: (1) a family with one 9th or 10th Grade student, (2) status as a “two-parent” family, defined as having two caregiving adults living in the same house for at least two years, (3) youth were required to live in one household continuously, (4) all participants were required to be able to read and write English fluently, (5) internet access and means to complete daily surveys at home, and (6) consent and assent to participate from the parent and adolescent, respectively. Adolescent participants were between 13 and 16 years of age ($M = 14.60$, $SD = 0.83$) and identified (via parent report) as White (83.4%), Asian (4.6%), African American/Black (4.6%), Native American/American Indian (0.7%), Hispanic/Latino (0.7%), Multiracial (5.3%), missing information (0.7%). Caregivers (92.7% mothers, 4.64% fathers, 1.30% stepmothers, 0.7% aunts, 0.7% foster mothers) had an average age of 43.4 ($SD=6.9$) years and self-identified as White (90.1%), Asian (3.3%), African American/Black (2.6%), Native American/American Indian (0.7%), Hispanic/Latino (0.7%), Multiracial (2.0%), and missing information (0.7%). Caregivers had a yearly family income ranging from ‘\$20,000’ to ‘\$125,000 or more’ ($Median =$ ‘70,000-79,999’). Caregivers' education spanned graduate or professional training (23.2%), college degree (27.8%), associate's degree or > one year college (30.5%), and high school degree or similar (15.2%), less than a high school degree (2.7%), or missing information (0.7%).

Procedure

Families were recruited through emails sent to parents from school principals. Interested parents received a web link with study information and a consent form. After confirming that the family met inclusion criteria, adolescents were contacted with a description of the study and an opportunity to assent or decline participation. If the adolescent assented, an email was sent to the youth with a baseline survey. Once the youth completed the baseline survey, the caregiver received his/her baseline survey. Upon completion of both baseline surveys, a 21-day daily diary protocol was initiated. Links to daily questionnaires were emailed separately to parents and adolescents at 7:00 PM each night in their time-zone, followed by a reminder text message or phone call to notify that the survey links had been sent. Participants were instructed to complete the daily survey before going to bed, although access links remained open until 9:00 AM the next morning. In cases where participants completed surveys the following morning, they were instructed to report on the previous day. Daily questionnaires took approximately 5 minutes to complete. Parents and adolescents were compensated with gift cards to Amazon.com or Wal-Mart (based on preference) at each study phase: \$25 each after completing the baseline assessment; \$2.50 for the first 4 daily surveys of each week, and \$5 for the last 3 surveys of each week (up to \$25 per week). Continued participation through the daily diary was further incentivized through the use of a raffle for which an iPad mini was available as a prize. Every week in which all daily questionnaires were completed resulted in one entry into the raffle drawing.

Measures

The present study made use of adolescents' reports of daily emotion from the daily diary component of the study as well as demographic and trait emotion regulation characteristics from the baseline surveys.

Depression. Adolescent depression was measured using the depression subscale of the Revised Child Anxiety and Depression Scale-Short Version (RCADS; Ebesutani et al., 2012). The measure was scored indicating the frequency with which symptoms of depression were experienced, with scores ranging from 1 ("Never") to 4 ("Always"). Higher values on this scale reflected higher levels of depressive symptoms. The depression subscale has shown favorable psychometric properties in previous work (Esbjorn et al., 2012) and for the current sample the measure demonstrated high reliability ($\alpha = .91$). Participants reported a mean score of 1.53 ($SD = 0.58$).

Difficulties in Emotion Regulation. Emotion regulation was measured using The Difficulties in Emotion Regulation Scale Short Form (DERS-SF; Kaufman et al., 2016). In line with the multidimensional nature of emotion regulation (e.g., Cole et al., 2004; Gratz & Romer, 2004), the DERS-SF incorporates 6 subscales in the measurement of emotion regulation, including 1) awareness and understanding of emotional responses, 2) acceptance of emotions, 3) the ability to control impulsive behaviors when experiencing negative emotions, 4) the ability to employ situationally appropriate emotion regulation strategies to meet one's goals, 5) the ability to engage in goal-directed behavior while experiencing negative emotions, and 6) the extent to which one is clear about which emotions one is experiencing. The total scale and subscales were scored to provide a score indicating the frequency with which emotion dysregulation is typically

experienced, with scores ranging from 1 ("Almost never") to 5 ("Almost always"). The total scale exhibited high reliability ($\alpha = .91$) and the subscales exhibited satisfactory reliability: awareness ($\alpha = .76$), non-acceptance ($\alpha = .84$), impulse control ($\alpha = .89$), goal-directed behavior ($\alpha = .83$), strategies ($\alpha = .88$), and clarity ($\alpha = .85$). Participants reported a mean total score of 2.05 ($SD = 0.73$). Mean scores for subscales are presented in Table 1.

Daily Emotion. Daily emotion was measured at the end of each day using items adapted from the Profile of Mood States - Adolescents (POMS-A; Terry et al., 2003) of the form, "How much of the time today did you feel...?" Four emotion scales, each consisting of two items – happiness (happy, content), depression (depressed, sad or blue), anxiety (worried, afraid), and anger (angry, annoyed) – were computed. A generalizability theory approach was taken to assess the reliability of the multi-item affect scales (see Bolger & Laurenceau, 2013). Happiness, depression, anger, and anxiety scales all exhibited reliable within-person variability in emotion over the course of the study, with reliability scores of .80, .81, .72, and .75, respectively. Taking the mean of each participants' daily reports, participants reported a mean happiness of 8.03 ($SD = 1.87$), a mean anger of 1.74 ($SD = 1.63$), a mean depression of 1.20 ($SD = 1.67$), and a mean anxiety of 1.31 ($SD = 1.73$).

Out of a possible 3171 days, complete data on daily emotion scales were available for 2823 days (89.03%). Complete data for the scales was available for an average of 18.70 ($SD=2.65$) days across participants. Pearson correlations between number of days completed and key study variables revealed that participants completing more days exhibited fewer emotion dysregulation difficulties as assessed by the DERS-SF ($r = -$

0.20, $p = .01$) and were older ($r = 0.18$, $p = .03$) relative to participants completing fewer days. Number of days completed was not significantly correlated with symptoms of depression ($r = -0.14$, $p = .08$). Independent samples t -tests revealed no significant difference in the number of days completed across genders ($t = -0.10$, $p = .92$).

Data Analysis

The daily emotion scales were lagged by one day to create previous day ($t-1$) happiness, depression, anxiety, and anger scores. Days with missing data on daily emotion were removed leaving a total of 2444 days of data. The intensive repeated measures data (2444 days nested within 151 persons) were analyzed using multilevel models (Snijders & Bosker, 2012). Both outcome and predictor variables were within-person standardized before the analysis to minimize the extent to which associations between symptoms of depression and network density were driven by individual differences in emotion variance (Pe et al., 2015). A second motivation for using within-person standardized variables was to render the coefficients representing different edges in the network comparable to one another, as raw regression coefficients are sensitive to scale and variance differences across variables (see Bringmann et al., 2016; Bulteel et al., 2016; Pe et al., 2015; Schuurman et al., 2016 for further discussions of this approach).

Separate multilevel models for each emotion outcome were used to estimate time-lagged associations among all emotions in order to create the emotion network density term. Using happiness as an example, models for emotion network density were constructed as

Level 1:

$$Happiness_{i,t} = \beta_{0i} + \beta_{1i}Happiness_{i,t-1} + \beta_{2i}Depression_{i,t-1} + \beta_{3i}Anxiety_{i,t-1} + \beta_{4i}Anger_{i,t-1} + e_{it}$$

where $Happiness_{i,t}$ is the emotion of interest (anxiety, depression, and anger were modeled in separate models of the same form) for person i on day t ; β_{1i} indicates within-person differences in happiness on day t associated with happiness at day $t-1$; β_{2i} indicates within-person differences in happiness on day t associated with depression at day $t-1$; β_{3i} indicates within-person differences in happiness on day t associated with anxiety at day $t-1$; β_{4i} indicates within-person differences in happiness on day t associated with anger at day $t-1$; and e_{it} are day-specific residuals that are allowed to autocorrelate (AR1). Parameters β_1 to β_4 allowed an estimation of the unique contribution of each emotion at day $t-1$ on happiness at day t .

Person-specific intercepts and associations (from the Level 1 model) were specified (at Level 2) as

Level 2:

$$\beta_{0i} = \gamma_{00}$$

$$\beta_{ki} = \gamma_{k0} + u_{ki}$$

where The γ s are sample-level parameters and the u s are residual between-person differences. The random effects were assumed to come from a multivariate normal distribution, estimating an unstructured covariance matrix of the random effects.

Individual participants' slopes were then extracted from the four multilevel models, taking the form $\beta_{ki} = \gamma_{k0} + u_{ki}$. As the interest was in the strength of the connections between emotion states regardless of directionality, the sum of the absolute value of the 16 slopes was calculated to represent the density of the emotion network for

each participant. Models were fit using the nlme package in R (Pinheiro et al., 2015) using maximum likelihood estimation. Pearson correlations were then computed to examine the associations between emotion network density, symptoms of depression, and difficulties in emotion regulation before multiple regression analyses were employed to examine the association between emotion network density and symptoms of depression while controlling for difficulties in emotion regulation, age, and gender.

To examine the robustness of the findings, an additional emotion network density index was created using person-mean deviated, rather than within-person standardized, versions of the affect scales. This approach has been taken in previous studies (e.g., Bringmann et al., 2016; Pe et al., 2015). In this approach, the emotion scales were manipulated to separate within- and between-person associations by creating time-invariant (between-person) and time-varying (within-person) versions of the variables (Bolger & Laurenceau, 2013). The time-invariant, between-person variables were calculated as the grand-mean centered individual mean scores of the variables across the study to capture between-person differences in average levels of emotion throughout the study. Time-varying, within-person variables were calculated as deviations from these between-person means, with a zero on these variables indicating a day of usual levels of that emotion. The association between network density and symptoms of depression was significant when using the within-person standardized versus within-person deviated variables but the correlation coefficient was larger when using the within-person deviated versions. In light of concerns of the role of variability in emotion scores across both persons and emotions on edge strength (Pe et al., 2015; Schuurman et al., 2016), we

continued with the more conservative, within-person standardized version of emotion network density.

RESULTS

Emotion Network Density: Descriptive Statistics

The mean emotion network density for the sample was 1.33 ($SD = 0.27$). Pearson correlations revealed that the number of days completed by participants was not systematically associated with emotion network density ($r=.11, p=.17$). Figure 1 provides an illustration of emotion network density for two participants. Each emotion state at time t is represented by a node in the network and relations between emotion states from time $t-1$ to time t are represented by weighted arrows (indicating connection strength) between nodes. The arrow from emotion state k to emotion state j is a visual depiction of the weight β_{kj} , expressing the strength of the association between emotion state k at time $t-1$ and emotion state j at time t . The thickness of the arrows indicates the strength of the association: the thicker the arrow between two nodes, the stronger the association.

Emotion Network Density: Associations with Emotion Regulation

Table 1 presents the correlations between emotion network density, symptoms of depression, as well as the DERS-SF total scale and subscales. Emotion network density was not significantly correlated with the DERS-SF total score ($r = .13, p = .12$). Examining correlations among emotion network density and subscales of the DERS-SF, emotion network density was significantly associated with non-acceptance ($r=.23, p<.01$) but not with the other subscales (all $ps > .05$).

Emotion Network Density: Associations with Depression

As hypothesized, emotion network density was significantly correlated with symptoms of depression ($r = .23, p = .01$), with larger emotion network density values associated with more symptoms of depression (Table 1). Multiple regression analysis (Table 2) indicated that depression symptoms were associated with emotion network density, DERS-SF total score, gender, and age, $F(4, 146) = 28.62, p < .01$. Adolescents exhibiting more depression symptoms had higher emotion network density scores ($\beta = 0.31, p = .02$) and greater difficulties in emotion regulation ($\beta = 0.49, p < .01$). Neither sex ($\beta = -0.06, p = .39$) nor age ($\beta = 0.02, p = .65$) were significantly associated with symptoms of depression.

DISCUSSION

The present study examined individual differences in emotion network density during adolescence and their associations with symptoms of depression. Partial support for the hypothesis that emotion network density would be associated with emotion regulation ability emerged such that emotion network density was associated with one subscale – the non-acceptance subscale – of the emotion regulation scale, but was not associated with either the total score or other subscales of the measure. As hypothesized, greater emotion network density was associated with more symptoms of depression. Notably, the association between emotion network density and symptoms of depression was significant above and beyond a trait measure of emotion dysregulation that has been widely used to assess emotion regulation difficulties (Gratz & Roemer, 2004; Kaufman et al., 2016).

Emotion Network Density and Emotion Regulation

Previous studies have speculated that emotion network density may partially result from difficulties in emotion regulation (Pe et al., 2015). Theory on emotion network density suggests that density indicates the extent to which the emotion system is rigid, resistant to both regulation efforts and situational demands (Kuppens & Verduyn, 2015; Pe et al., 2015). By examining the association between emotion network density and difficulties in emotion regulation, the present study was able to explore one potential source of input into the emotion system as a mechanism underlying individual differences in emotion network density. The role of emotion regulation difficulties in individual differences in emotion network density was partially supported in that, while network density was not correlated with the total emotion regulation scale nor the majority of its subscales, it was significantly correlated with the non-acceptance subscale.

Acceptance refers to openness to emotional experiences, even if those experiences are uncomfortable. The association between emotion network density and non-acceptance may be explained by the tendency for quicker recovery of experimentally-evoked emotions relative to other emotion regulation approaches such as suppression (Campbell-Sills et al., 2006; Liverant et al., 2008). In these studies, acceptance modulated the duration of emotion states, a characteristic that would result in lower coefficients *within* emotion states across time. In terms of the cross-lagged components of the emotion network (i.e., associations *between* affective states across time), a feature of non-acceptance is the tendency to have secondary emotional responses to one's emotions (Gratz & Roemer, 2004), for example responding to the experience of anxiety with anger. Indeed, items on the DERS-SF non-acceptance scale capture the tendency to experience

secondary emotion reactions (e.g., "When I'm upset, I become irritated with myself for feeling that way"). Thus, the tendency for participants high in non-acceptance to experience secondary emotional reactions may be a process through which between-person differences in non-acceptance resulted in higher coefficients *between* emotional states across time.

Looking forward, it is important to note that emotion dynamics may be interpreted as an indicator of the person, the context, and person-context transactions (Koffer & Ram, 2015). Thus, when attempting to uncover the sources of the greater network density in adolescents exhibiting greater symptoms of depression, the consideration of both the individual and the context in which the adolescent is embedded will be essential for teasing apart the processes driving greater affect network density.

Emotion Network Density and Symptoms of Depression

By demonstrating that emotion network density was associated with symptoms of depression in adolescents, our results extend findings in adults that denser emotion networks are associated with major depressive disorder (Pe et al., 2015). For both adolescents and adults, then, depression is characterized by dense temporal connections within and between emotions that may encourage the spread of emotion across time and states – resulting in a self-perpetuating emotion system (Kuppens & Verduyn, 2015). With emotions responding to themselves rather than to ongoing events of potential importance, the flexibility of the emotional system characterized by adaptive responding to changing environmental demands is undermined.

Linking greater network density with greater symptoms of depression during adolescence adds to findings that have shown that, despite differences in emotion

dynamics across developmental periods (e.g., Larson et al., 1980; Maciejewski et al., 2015), individual differences in emotion dynamics associated with psychopathology in adults (e.g., inertia; Kuppens et al., 2010; Silk et al., 2003; Neumann et al., 2011) also demonstrate relevance for understanding psychopathology during adolescence. A promising next step will be to examine whether changes in emotion network density within-person, over time can act as a warning sign for the onset of clinically relevant episodes of depression in adolescents as has been observed in adults (Wichers et al., 2016).

Limitations and Future Directions

It is important to consider the findings in light of the study's strengths and limitations. The collection of data over many days in many participants is a strength of the current study. Collecting data on a greater number of emotion items will provide more detailed insight into emotion dynamics across a broader range of emotions. The focus on day-to-day fluctuations in emotions overcomes a number of challenges in the modeling daily diary data. For example, the assumption of equally spaced measurement intervals is more easily defended when data are reported at the end of each day relative to multiple times throughout the day and then not at all during the night. However, the focus on day-to-day dynamics may miss less marked patterns of emotion transfer across time. An alternative approach would be to undertake a more intensive (e.g., multiple measurements per day; Pe et al., 2015) measurement protocol. Depressive symptoms were measured concurrently with the intensive longitudinal data. As such, developmental inferences on the association between emotion network density and symptoms of psychopathology are not warranted until longitudinal analyses are employed.

Despite advances in emotion network methodology (Bringmann et al., 2016), some limitations remain that must be kept in mind when interpreting the current results. Individual differences in the variance of the emotion variables as well as differences in variance across the emotion items can impact the coefficients indicating the strength between emotions (Bulteel et al., 2016; Schuurman et al., 2016). By within-person standardizing the emotion items before modeling the networks we minimized the effect of scale differences across persons and emotion states. Arriving at the same substantive conclusions for associations between depression and emotion network density with the use of the person-mean deviated versions of the emotion variables also increase our confidence in the conclusions drawn here.

Conclusions

In summary, the present study extends previous examinations of emotion network density in adults by demonstrating associations between emotion network density and symptoms of depression in adolescents. The finding that emotion network density offers additional predictive value in understanding risk for depression, above and beyond a trait measure of emotion regulation, highlights the added value of examining emotion regulation through emotion dynamics collected through intensive repeated measures. Finally, findings of associations between emotion network density and non-acceptance begin the task of teasing apart the processes that give rise to the emotion network density.

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Figure Captions

Figure 1. Graphic display of emotion network dynamics for two participants. The 4 emotion states are: Hpp = happiness, Anx = anxiety, Ang = anger, Dpr = depression. The thickness of the arrows represents the strength of the connections between any two pairs of emotions (one emotion state at time $t-1$ and the other at time t across days). To facilitate comparisons between both networks, the maximum thickness of the arrows was set to the maximum connection strength across both networks (a value of 0.38). The network on the left is associated with an overall affect network density score of 1.06 while the network on the right has a score of 1.60. These values were chosen to represent networks with density values at ± 1 standard deviation (0.27) around the mean (1.33). Thus, the network on the left is a less dense emotion network relative to the network on the right. The networks were constructed using qgraph in R (Epskamp et al., 2012).

Table 1

Emotion network density, symptoms of depression, and emotion regulation: Correlations and descriptive statistics

Variables	1	2	3	4	5	6	7	8	9
1. Network Density	1								
2. Depression	.22**	1							
3. DERS-SF Total	.13	.64**	1						
4. Non-Acceptance	.23**	.57**	.78**	1					
5. Goals	.09	.50**	.76**	.54**	1				
6. Strategies	.08	.65**	.87**	.66**	.69**	1			
7. Clarity	.07	.47**	.78**	.63**	.44**	.62**	1		
8. Impulse	-.01	.39**	.77**	.52**	.56**	.68**	.49**	1	
9. Awareness	.08	.19*	.36**	.06	.03	.09	.24**	.13	1
Variables	1	2	3	4	5	6	7	8	9
<i>Mean</i>	1.33	1.53	2.05	1.94	2.48	1.88	1.84	1.67	2.50
<i>Standard Deviation</i>	0.27	0.58	0.73	1.00	1.08	1.06	0.95	0.93	1.03

Notes: DERS-SF = Difficulties in Emotion Regulation Scale Short Form; $N = 151$; * $p < .05$; ** $p < .01$.

Table 2.

Correlations of mean emotions during the daily diary, symptoms of depression, and emotion network density

Variables	1	2	3	4	5
1. Network Density	1				
2. RCADS	.22**	1			
3. Anger	.18*	.57***	1		
4. Anxiety	.28***	.66***	.76***	1	
5. Happiness	-.21**	-.58***	-.60***	-.52***	1
6. Depression	.19*	.68***	.83***	.85***	-.69***

Notes: RCARDS = Revised Child Anxiety and Depression Scale-Short Version; $N = 151$; * $p < .05$; ** $p < .01$; *** $p < .001$. Emotions are the mean of the participant time series for each emotion across the daily diary phase of the study.

Figure 1.