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Eating Disorder Core Symptoms and Symptom Pathways Across Developmental Stages: A Network Analysis

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Eating disorders (EDs) often develop during adolescence and early adulthood but may persist, arise, or reemerge across the life span. Research and treatment efforts primarily focus on adolescent and young adult populations, leaving large knowledge gaps regarding ED symptoms across the entire developmental spectrum. The current study uses network analysis to compare central symptoms (i.e., symptoms that are highly connected to other symptoms) and symptom pathways (i.e., relations among symptoms) across five developmental stages (early adolescence, late adolescence, young adulthood, early-middle adulthood, middle-late adulthood) in a large sample of individuals with EDs ($N = 29{,}902$; $N = 32{,}219$) in two network models. Several symptoms related to overeating, food avoidance, feeling full, and overvaluation of weight and shape emerged as central in most or all developmental stages, suggesting that some core symptoms remain central across development. Despite similarities in central symptoms, significant differences in network structure (i.e., how symptom pathways are connected) emerged across age groups. These differences suggest that symptom interconnectivity (but not symptom severity) might increase across development. Future research should continue to investigate developmental symptom differences in order to inform treatment for individuals with EDs of all ages.

General Scientific Summary

Connections between eating disorder symptoms vary across stages of development. Consistent with Habit Formation Theory, symptoms were more tightly connected in older individuals, who have on average a longer duration of illness. In contrast, eating disorder central symptoms (symptoms related to overeating, food avoidance, fullness, and overvaluation of weight and shape) were relatively consistent across age groups.

Keywords: eating disorder symptoms, development, age, network analysis, eating disorders

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The present study is a new analysis of previously analyzed data. This study is the investigation of developmental differences in eating disorder symptoms using network analysis using this dataset. No other papers have addressed similar questions as those addressed in this article. All study procedures were approved by the University of Kansas Institutional Review Board (Study IRB STUDY00003260). Authors complied with APA ethical standards in the treatment of their participants. The manuscript has not been and is not posted on a website. Jenna P. Tregarthen is a co-founder and shareholder of Recovery Record, Inc. Jenna P. Tregarthen made a substantial contribution as part of data collection and curation and approved the final manuscript, but she did not participate in the analysis, interpretation, or drafting of the manuscript. Kelsie T. Forbush received an industry-sponsored grant from Recovery Record, Inc. No other authors have conflicts of interest to disclose.

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Eating disorders (EDs) are serious mental illnesses associated with negative health consequences, significant impairment, and high mortality (Crow et al., 2009; Rome & Ammerman, 2003; Stice, Marti, & Rohde, 2013). Peak age of ED onset is during adolescence, between 16 and 20 years of age (Stice et al., 2013). Although EDs most commonly develop during this period, evidence suggests that eating pathology may persist, return, or develop throughout an individual's life (Fulton, 2016; Patrick & Stahl, 2009). Indeed, studies indicate that ED symptoms occur across all developmental stages, with approximately 11% of adults aged 42–55 and 4% of adults aged 60–70 engaging in ED behaviors, such as binge eating, laxative/diuretic misuse, or self-induced vomiting (Mangweth-Matzek et al., 2006; Marcus, Bromberger, Wei, Brown, & Kravitz, 2007). The presence of disordered eating among middle and older adults suggests that it is important to examine EDs across the full developmental spectrum; however, to date, research has primarily focused on EDs in adolescence and early adulthood.

Past research suggests that ED symptoms may change across development. However, the nature of these differences remains unclear. In terms of diagnoses, older individuals are more likely to be diagnosed with binge eating disorder, as compared to younger individuals with EDs (Jenkins & Price, 2018). Additionally, diagnostic migration is extremely common in EDs, which suggests that symptomatology may shift as the person and illness develop (Castellini et al., 2011; Fichter & Quadflieg, 2007). In terms of severity, some research suggests that disordered eating behaviors, body dissatisfaction, and distorted cognitions surrounding food decline with age (Gadalla, 2008; Forman & Davis, 2005; Tiggemann & McCourt, 2013). Reduction of ED cognitions may be related to the changing social environment over the life span. In one study, the association between negative commentary about one's weight and shape and bulimic symptoms diminished with older age (Tzoneva, Forney, & Keel, 2015).

However, other studies indicated body dissatisfaction and dieting behaviors remain prevalent and may strengthen with age (e.g., Fulton, 2016). Indeed, research supports that overvaluation of weight and shape is pervasive among middle age and older adults (Forman & Davis, 2005; Patrick & Stahl, 2009; Mangweth-Matzek et al., 2006). The Habit Formation Theory of EDs suggests that maladaptive eating behaviors may begin as goal-driven (e.g., dieting to lose weight), but with repetition, these behaviors (e.g., restriction), coupled with the reward (e.g., praise from others on losing weight), develop into a deeply engrained habit (Walsh, 2013). Similarly, binge eating and purging behaviors may begin impulsively to cope with negative emotions but can develop into compulsive rituals with repetition (Pearson, Wonderlich, & Smith, 2015). Thus, Habit Formation Theory posits that maladaptive eating behaviors and cognitions will become more deeply engrained and habitual in later developmental stages. Indeed, studies indicate that older age of onset and longer duration-of-illness are associated with poor treatment outcomes (Noordenbos, Oldenhave, Muschter, & Terpstra, 2002; Norring & Sohlberg, 1993), highlighting the clinical importance of researching eating pathology across development.

Overall, the current state of eating disorder research provides an incomplete picture of cognitions and behaviors across the life span. Thus, additional research examining the differences in eating disorder symptoms across developmental stages is urgently needed. Specifically, it is unknown how *specific* symptoms and symptom relationships might change across developmental periods to maintain ED psychopathology.

One novel way to conceptualize EDs is network theory. Network analysis (NA) is a statistical methodology based on network theory, which conceptualizes psychopathology as a web of interconnecting nodes (symptoms) and edges (associations between symptoms) that are theorized to maintain a specific illness state (Borsboom, 2017). NA allows researchers to identify specific relationships among many symptoms at once and provides opportunities to visualize illness pathways (relationships among individual symptoms) and identify central symptoms (symptoms that are highly connected with other symptoms in the network). NA can also identify if two networks are significantly different from each other in structure (i.e., if two symptoms are similarly associated in both networks) and global strength (how strongly symptoms are associated with each other; van Borkulo et al., 2015). This technique allows researchers to investigate if (and how) two populations or subgroups of a population differ in symptom connectedness.

Several studies have used NA to understand ED psychopathology. These studies found body checking (Forbush, Siew, & Vitevitch, 2016), fear of weight gain (Elliott, Jones, & Schmidt, 2018; Forrest, Jones, Ortiz, & Smith, 2018; Levinson et al., 2017), and other symptoms related to overvaluation of weight and shape (DuBois, Rodgers, Franko, Eddy, & Thomas, 2017; Elliott et al., 2018; Forrest et al., 2018; Goldschmidt et al., 2018; Wang, Jones, Dreier, Elliott, & Grilo, 2018) to be central, maintaining symptoms, consistent with the cognitive–behavioral theory of EDs (Cooper & Shafran, 2008; Fairburn, 2008). A few additional studies have identified additional important symptoms, such as dietary restraint (Goldschmidt et al., 2018; Solmi et al., 2018), interoceptive awareness, (Olatunji, Levinson, & Calebs, 2018; Solmi et al., 2018), and ineffectiveness (Olatunji et al., 2018; Solmi et al., 2018; Solmi, Collantoni, Meneguzzo, Tenconi, & Favaro, 2019), and the relationships among depression, anxiety, and ED symptoms (Solmi et al., 2018, 2019).

Although NA has been applied to increase the broad understanding of eating pathology, no research has examined differences in network models of ED symptoms across developmental stages. Past research suggests that there may be unique differences in ED presentations across the life span, including diagnostic differences, physical changes, and differences in treatment outcomes (Castellini et al., 2011; Forman & Davis, 2005; Hudson & Pope, 2018; Jenkins & Price, 2018; Peat, Peyerl, & Muehlenkamp, 2008). Thus, it seems likely that ED symptom relationships may also differ across developmental stages. Better understanding of the differences in central ED symptoms across developmental stages could help determine if alternative treatments would be more beneficial for different age groups.

The current study utilizes NA to examine ED symptoms in five distinct developmental stages: early adolescence (11–14), late adolescence (15–18), young adulthood (19–25), early-middle adulthood (26–45), and middle-late adulthood (46+). These age ranges represent unique developmental stages in several aspects, including social environment, physiological and neurological development, maturity, and autonomy (Blonigen, Carlson, Hicks, Krueger, & Iacono, 2008; Steinberg, 2005; Williams & Currie, 2000). We examine symptom relationships across two widely used ED mea-

sures: the Eating Pathology Symptoms Inventory (EPSI; Forbush et al., 2013) and Eating Disorder Examination Questionnaire (EDE-Q; Fairburn & Beglin, 1994). Both questionnaires are considered "gold-standard" measures of ED symptoms and are frequently used for network investigations (DuBois et al., 2017; Forbush et al., 2016; Forrest et al., 2018), yet they assess slightly different aspects of ED symptoms, such that the EDE-Q is based on the cognitive–behavioral model of EDs and the EPSI is designed to be a multidimensional assessment of ED symptoms. Thus, we include both measures to allow for a more comprehensive overview of ED symptoms and to gain insight into the replicability of networks.

We hypothesized that symptoms that were central in past studies using NA (e.g., overvaluation of weight and shape; Levinson, Vanzhula, Brosof, & Forbush, 2018) would remain central regardless of age, as suggested by the literature (Forman & Davis, 2005; Patrick & Stahl, 2009; Mangweth-Matzek et al., 2006). Further, we hypothesized that there would be a significant difference in network structure across networks. Despite some common threads across EDs, specific connections between symptoms are likely to differ across developmental stages, given what the literature has described in terms of differences in symptom severity and treatment effectiveness (Hudson & Pope, 2018; Jenkins & Price, 2018; Peat et al., 2008; Forman & Davis, 2005). For example, although fear of weight gain may remain central across diverse ED presentations, the connection between fear of weight gain and binge eating may become stronger over time, consistent with the Habit Formation Theory (Walsh, 2013). This change would result in differences in network structure, which has implications for implementing effective treatments across age groups. Additionally, we predict that the global strength would increase for networks with older participants compared to younger participants, reflective of Habit Formation Theory, indicating increased severity across developmental stages.

Method

Participants

Participants were Recovery Record users (N = 29,902; N = 32,219), a smartphone application that is based on cognitive–behavioral treatment for EDs (Tregarthen, Lock, & Darcy, 2015). Participants provided consent for data to be used for research purposes when they agreed to the "Terms and Conditions" in the initial application setup. Participants who completed the EPSI (n = 29,902) were 11 to 85 years old (M = 26.23, SD = 10.46), and 94.0% identified as female. These participants reported their average length of ED was 9.71 years (SD = 9.72, range = 0–65 years). Recovery Record allows users to connect their account with a clinician in order to share information and inform treatment planning. In our sample, 34.5% of participants had accounts connected with a treatment provider and had an official diagnosis of an ED based on clinician-report.

Participants who completed the EDE-Q (n = 32,219) were 11 to 79 years old (M = 23.43, SD = 8.89), and 96.5% identified as female. Average length of ED was 7.60 years (SD = 8.23, range = 0–60 years). In the present sample, 8.8% of participants had accounts connected with a treatment provider and had an official diagnosis of an ED based on clinician-report. See Table 1 for

Table 1
Demographic Breakdown

Demographic characteristic	Early adolescence *n* (%)	Late adolescence *n* (%)	Young adult *n* (%)	Early-middle adult *n* (%)	Middle-late adult *n* (%)
EDE-Q	1523 (100)	9838 (100)	11709 (100)	7955 (100)	1194 (100)
Gender					
Female	1468 (96.4)	9498 (96.5)	11310 (96.6)	7671 (96.4)	1131 (94.7)
Male	42 (2.8)	248 (2.5)	288 (2.9)	228 (2.9)	56 (4.7)
Missing	13 (.9)	92 (.9)	111 (.7)	56 (.7)	7 (.6)
Diagnosis					
AN	13 (.9)	85 (.9)	159 (1.4)	133 (1.7)	19 (1.6)
BN	2 (.1)	37 (.4)	99 (.8)	104 (1.3)	12 (1.0)
BED	4 (.3)	12 (.1)	49 (.4)	104 (1.3)	55 (4.6)
Other	3 (.2)	42 (.4)	93 (.8)	102 (1.3)	18 (1.5)
Missing	1501 (98.6)	9662 (98.2)	11309 (96.6)	7522 (94.6)	1090 (91.3)
Duration of illness (*M*[*SD*])	1.71 (1.71)	2.92 (2.27)	5.82 (3.96)	13.86 (8.37)	29.00 (14.60)
EPSI	1028 (100)	6171 (100)	10701 (100)	9929 (100)	2073 (100)
Gender					
Female	959 (93.3)	5786 (93.8)	10108 (94.5)	9412 (94.8)	1857 (89.6)
Male	46 (4.5)	228 (3.7)	381 (3.6)	438 (4.4)	201 (9.7)
Missing	23 (2.2)	157 (2.5)	212 (2.0)	79 (.8)	15 (.7)
Diagnosis					
AN	152 (14.8)	796 (12.9)	1456 (13.6)	995 (10.0)	172 (8.3)
BN	30 (2.9)	307 (5.0)	870 (8.1)	825 (8.3)	81 (3.9)
BED	31 (3.0)	165 (2.7)	514 (4.8)	1144 (11.5)	527 (25.4)
Other	62 (6.0)	354 (5.7)	795 (7.4)	830 (8.4)	222 (10.7)
Missing	753 (73.2)	4549 (73.7)	7066 (66.0)	6134 (61.8)	1071 (51.7)
Duration of illness (*M*[*SD*])	2.06 (2.11)	3.19 (2.44)	6.05 (4.12)	14.54 (8.58)	29.12 (15.20)

Note. EDE-Q = Eating Disorder Examination Questionnaire; EPSI = Eating Pathology Symptoms Inventory; AN = anorexia nervosa; BN = bulimia nervosa; BED = binge eating disorder.

participants' gender, ED diagnoses, and duration of illness across developmental categories.

Measures

EPSI. The EPSI is a 45-item multidimensional measure designed to assess ED symptoms. The EPSI has eight scales corresponding to unique facets of eating pathology: Body Dissatisfaction (i.e., satisfaction with body shape and body parts; e.g., hips, thighs), Binge Eating (i.e., tendency to overeat or eat mindlessly), Cognitive Restraint (i.e., attempting to restrict eating, whether successful or not), Excessive Exercise (i.e., intense or compulsive exercise), Restricting (i.e., efforts to avoid or reduce eating), Purging (i.e., self-induced vomiting and laxative/diuretic use), Muscle Building (i.e., cognitions and behaviors [supplement use] related to increasing muscularity), and Negative Attitudes Toward Obesity (i.e., negative judgment of individuals who are overweight/obese). Between 32.6% and 73.6% of our sample scored above EPSI subscale means in an ED treatment sample (Forbush et al., 2013). Two scales of the EPSI, Negative Attitudes Toward Obesity and Muscle Building, were not included in the Recovery Record app; thus, these items were not included in the network. The EPSI has excellent convergent and discriminant validity, as well as excellent test-retest reliability (Forbush et al., 2013). The internal consistency of all items included in the EPSI network was adequate for the current sample ($\alpha = .73$).

EDE-Q. The EDE-Q version 6.0 is a 28-item self-report questionnaire designed to assess ED behaviors and thoughts. This version of the EDE-Q has four scales: Eating Concern (i.e., interfering thoughts about food, eating, or calories), Shape Concern (i.e., interfering thoughts about shape), Weight Concern (i.e., interfering thoughts about weight), and Restraint (i.e., attempts to reduce food intake; e.g., skipping meals, food rules). The mean EDEQ global score in our sample is 4.17 ($SD = 1.10$), and 63.3% ($n = 20{,}390$) of our sample scored above the recommended clinical cutoff (a score of 4.0 or higher) for EDs (Fairburn, Wilson, & Schleimer, 1993). One EDE-Q item (15) was excluded because it measures the same symptom (binge eating) as the previous question. Networks should not include two questions targeting the same symptom because it may artificially inflate centrality, potentially leading to false interpretation of that symptom as central (Fried & Cramer, 2017). The EDE-Q has demonstrated excellent test-retest reliability and internal consistency (Luce & Crowther, 1999) and good criterion and concurrent validity (Mond, Hay, Rodgers, Owen, & Beumont, 2004). The internal consistency of all items included in the EDE-Q network was good for the current sample ($\alpha = .86$).

Procedure

Participants used the Recovery Record application to self-monitor ED cognitions and behaviors. The application encourages monthly completion of the EDE-Q and the EPSI. The present study used data from the initial completion of EDE-Q and EPSI by participants using the mobile application.

Participant data were categorized into five developmental stages: early adolescence (11–14), late adolescence (15–18), young adulthood (19–25), early-middle adulthood (26–45), and middle-late adulthood (46+). Our ranges may not fully distinguish between all stages of development because we had few participants above the age of 45 ($n = 1{,}194$ for EPSI, $n = 2{,}073$ for EDE-Q) relative to the entire sample, so we used 45 as a cutoff for middle-late adulthood in order to ensure a large sample size for the networks. Using younger age ranges is not uncommon for clinical studies on EDs due to difficulty recruiting older adults with EDs (Forman & Davis, 2005; Jenkins & Price, 2018).

Glasso networks using the EDE-Q and EPSI were estimated at each developmental stage using the "estimateNetwork" function in the bootnet package in R (Epskamp, Maris, Waldorp, & Borsboom, 2018). The Glasso function estimates partial correlations between nodes, meaning each correlation is unique, accounting for all other symptoms in the network while minimizing spurious relationships. We first created networks using the default setting (cor_auto), which uses polychoric correlations. However, because some networks did not have adequate stability, we estimated the networks again using Spearman correlations to obtain stable networks, as suggested by Epskamp and Fried (2018). Stability estimates were calculated using the bootnet package in R (Epskamp et al., 2018).

Three indices of centrality were calculated using the "centralityplot" function in the qgraph package in R: strength (i.e., the sum of the absolute value of all of a node's edges), closeness (i.e., degree of direct connections to other nodes), and betweenness (i.e., degree to which a node falls on the path between other nodes; Epskamp, Cramer, Waldorp, Schmittmann, & Borsboom, 2012). We interpret only strength centrality because it was the most stable, as has been done in prior NA investigations (e.g., DuBois et al., 2017; Epskamp et al., 2012). Centrality difference tests were conducted using the bootnet package in R (Epskamp et al., 2018) to determine if central symptoms were significantly more central than other symptoms. We included three to six central symptoms for each network based on the network centrality difference test. The number of symptoms included per network is based on sharp observable decreases in centrality differences among top symptoms that were used as cutoffs for inclusion. We did not use a standard cutoff value across networks due to internetwork variability.

Differences between networks across developmental stages were identified using the NetworkComparisonTest package in R (van Borkulo et al., 2015). Three metrics were utilized to analyze network differences: network invariance test (*M*; i.e., significant differences in the maximum edge strength in the networks), edge invariance test (*E*; i.e., significant differences between specific edges in the networks), and global strength invariance test (*GSI;* i.e., significant differences in the sum of the edge strengths; van Borkulo et al., 2015). Edge invariance was calculated for networks with significant network invariance in order to quantify the nature of these structural differences. Global strength is a particularly useful measure, as it may be related to symptom severity (van Borkulo et al., 2015).

A one-way ANOVA was conducted across developmental stages for both the EDE-Q and EPSI to investigate whether significant differences in symptom severity across groups were related to global strength across networks, as has been theorized (van Borkulo et al., 2015). We conducted these analyses using the EDE-Q global score, as factor validity is strongest for the global index rather than the four subscales (Aardoom, Dingemans, Sloft Op't Landt, & Van Furth, 2012) and six EPSI subscales, as the

EPSI was designed as a multidimensional measure of eating pathology, rather than a global subscale of severity (Forbush et al., 2013). A post hoc Bonferroni correction was used for multiple comparisons. The cutoff value after this correction is $p = .007$.

Results

Networks and Stability

See Figure 1 for EPSI networks and Figure 2 for EDE-Q networks. Table 2 includes descriptions of each of the EPSI and EDE-Q items. Stability for strength was excellent (strength = .75) for all the EPSI and EDE-Q networks (Epskamp, Borsboom, & Fried, 2018).

Central Symptoms

EPSI. See Figure 3 for the strength centrality of all symptoms in the EPSI networks. All central symptoms were significantly more central than other symptoms in the network at $p < .05$. Overeating and feeling full after eating a small amount of food emerged as central symptoms across every developmental stage. Avoiding high calorie foods and planning days around exercise are central symptoms in late adolescence, young adulthood, early-middle adulthood, and middle-late adulthood. Fasting is a central symptom in early adolescence, late adolescence, young adulthood, and early-middle adulthood. Stuffing oneself to the point of feeling sick is a central symptom in young adulthood, early-middle adulthood, and middle-late adulthood. The most central symptoms in the EPSI networks are described in Table 3.

EDE-Q. See Figure 4 for the strength centrality of all symptoms in the EDE-Q networks. All central symptoms were significantly more central than other symptoms in the network at $p < .05$. Desire for an empty stomach emerged as a central symptom across every developmental stage. Concentration problems due to weight and shape is a central symptom in early adolescence, late adolescence, young adulthood, and early-middle

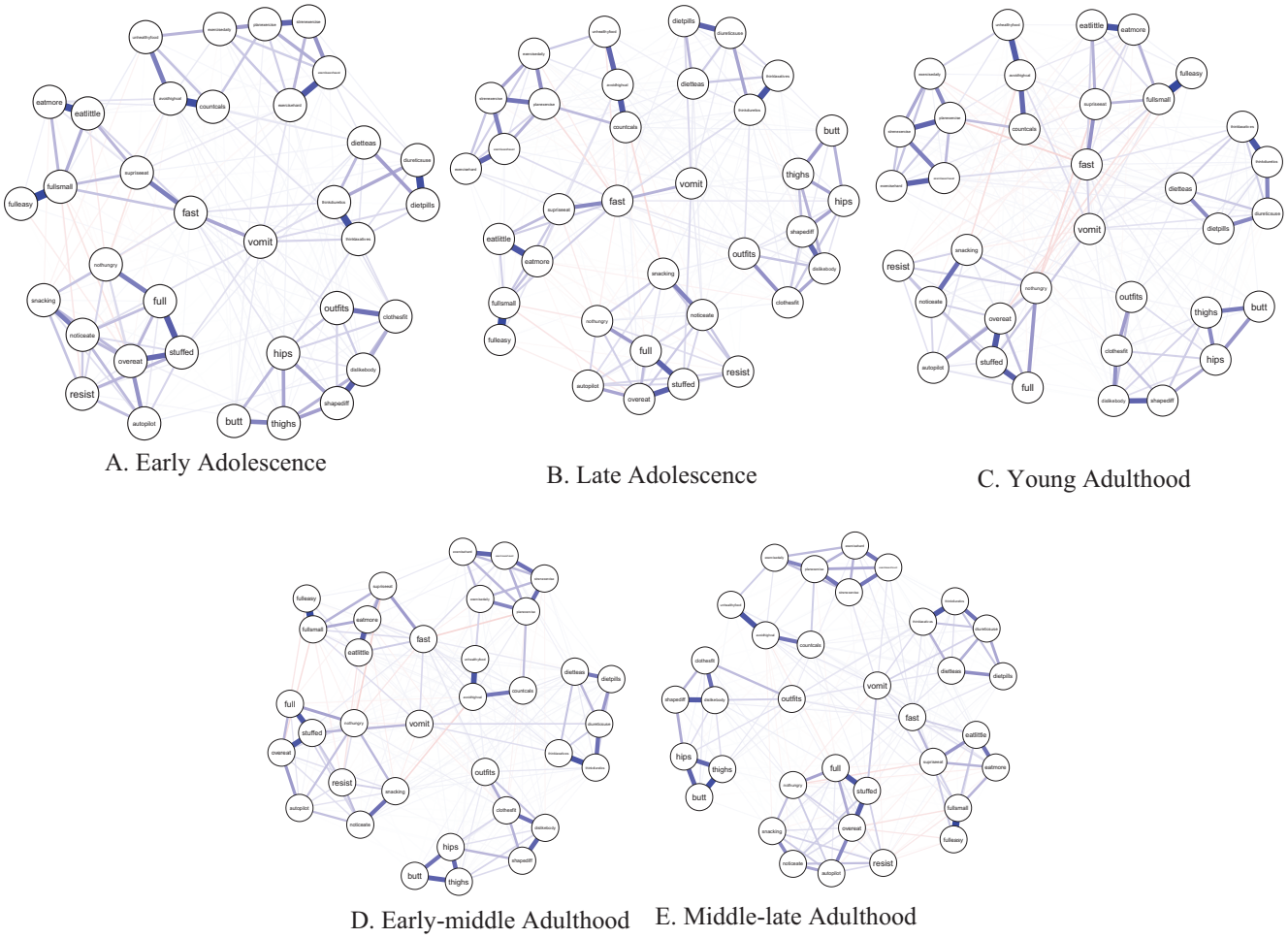

Figure 1. EPSI networks for (A) early adolescence (11–14), (B) late adolescence (15–18), (C) young adulthood (19–25), (D) early-middle adulthood (26–45), and (E) middle-late adulthood (46+). Blue (solid) edges represent positive partial correlations. Red (dashed) lines represent negative partial correlations. Line thickness represents the strength of the partial correlation. See Table 2 for EPSI items corresponding to each node. See the online article for the color version of this figure.

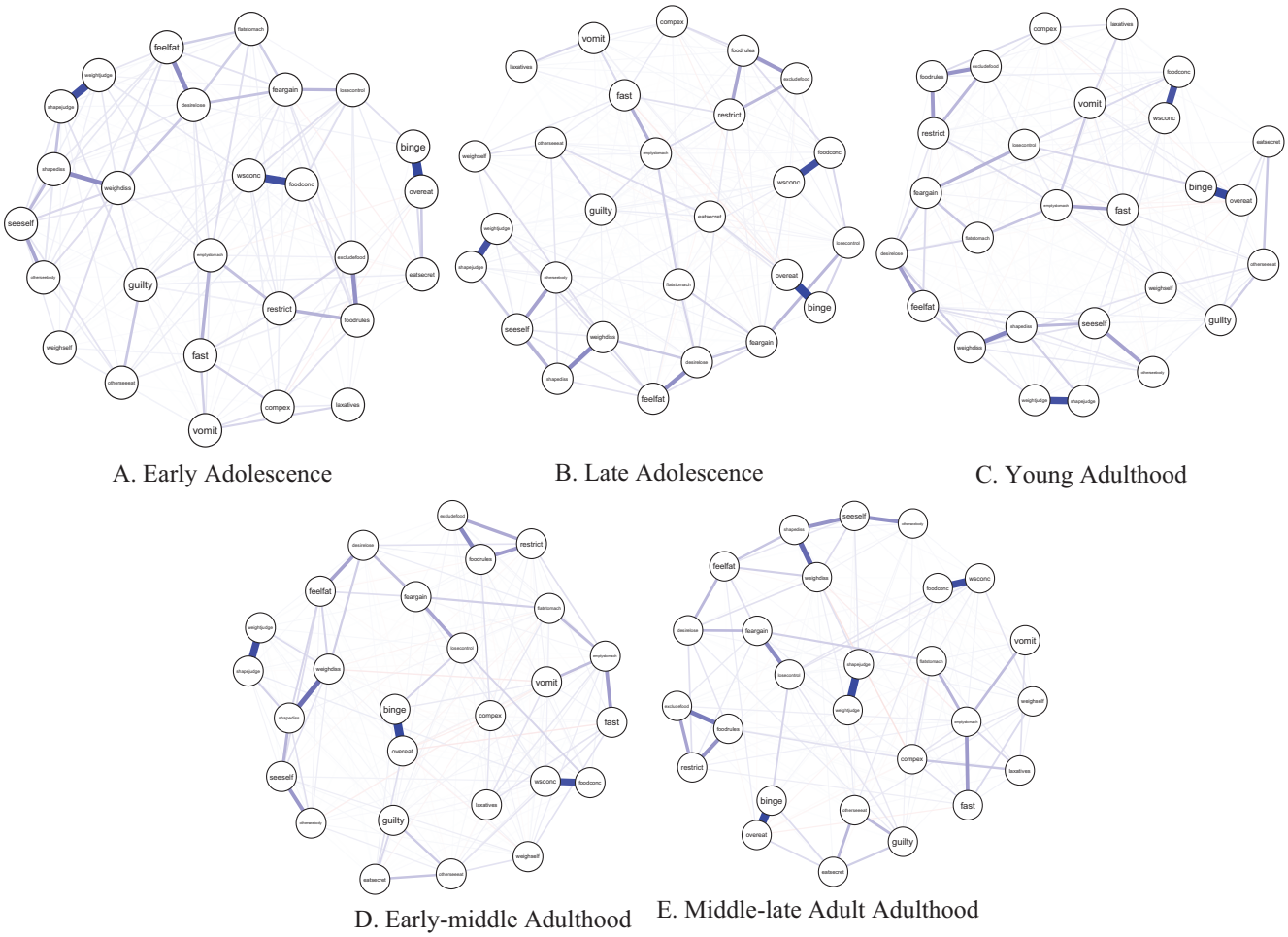

Figure 2. EDE-Q networks for (A) early adolescence (11–14), (B) late adolescence (15–18), (C) young adulthood (19–25), (D) early-middle adulthood (26–45), and (E) middle-late adulthood (46+). Blue (solid) edges represent positive partial correlations. Red (dashed) lines represent negative partial correlations. Line thickness represents the strength of the partial correlation. See Table 2 for EDE-Q items corresponding to each node. See the online article for the color version of this figure.

adulthood. Feeling dissatisfied about one's weight is a central symptom in early adolescence, young adulthood, early-middle adulthood, and middle-late adulthood. Overeating is a central symptom in late adolescence, young adulthood, early-middle adulthood, and middle-late adulthood. Desire to lose weight is a central symptom in early and late adolescence. Judgment of self due to shape is a central symptom in early adolescence. Binge eating is a central symptom in young adulthood. Dissatisfaction about one's shape is a central symptom in middle-late adulthood. The most central symptoms in the EDE-Q networks are described in Table 4.

EPSI networks. The network invariance test indicated that the early adolescence network was significantly different than late adolescence ($M = 0.12$, $p = .05$), young adulthood ($M = 0.52$, $p = .05$), early-middle adulthood ($M = 0.23$, $p < .001$), and middle-late adulthood ($M = 0.29$, $p < .001$). The late adolescence network was significantly different from early-middle adulthood ($M = 0.17$, $p < .001$) and middle-late adulthood ($M = 0.24$, $p < .001$), but not young adulthood ($p > .05$). The young adulthood network was not significantly different from early-middle adulthood or middle-late adulthood ($p > .05$). The early-middle adulthood network was significantly different than middle-late adulthood ($M = 0.10$, $p = .02$).

The edge invariance test indicated that two edges were significantly different ($p < .05$) between early adolescence and late adolescence, one edge significantly differed between early adolescence and young adulthood, 16 edges significantly differed between early adolescence and early-middle adulthood, 13 edges significantly differed between early adolescence and middle-late adulthood, 20 edges significantly differed between late adolescence and early-middle adulthood, 19 edges significantly differed between late adolescence and middle-late adulthood, and two edges significantly differed between early-middle adulthood and middle-late adulthood. See online supplemental materials for all significantly different edges and corresponding *E*-values. The Global Strength Invariance test indicated that there were no significant differences in global strength among the EPSI networks of different developmental stages ($p > .05$).

EDE-Q. The structure of the early adolescence network was significantly different than young adulthood ($M = 0.15$, $p = .001$), early-middle adulthood ($M = 0.17$, $p < .001$), and middle-late adult-

Table 2
Network Node (i.e., Symptom) Abbreviations

EPSI	
clothesfit	Dislike how clothes fit
unhealthyfoods	Attempt to exclude "unhealthy" foods
nothungry	Ate when not hungry
eatlittle	Told that I do not eat much
exercisedaily	Felt the need to exercise nearly daily
supriseeat	People would be surprised by how little I ate
exercisehard	Push myself hard when exercising
snacking	Snacked without realizing
fulleasy	Got full easily
thinkdiuretics	Considered taking diuretics
outfits	Tried on different outfits because of how I looked
thinklaxatives	Thought laxatives are good to lose weight
dietteas	Used diet teas or cleansing teas
dietpills	Used diet pills
dislikebody	Dislike how my body looked
full	Ate until uncomfortably full
countcals	Counted calories
planexercise	Planned days around exercising
butt	Thought butt was too big
thighs	Dislike size of thighs
shapediff	Wished shape of body was different
vomit	Vomited to lose weight
noticeate	Did not notice how much I ate until after
strenexercise	Engaged in strenuous exercise at least 5 days per week
fullsmall	Got full after eating a small amount of food
hips	Dissatisfied with the size of hips
eatmore	Others encouraged to eat more
resist	Felt I could not resist eating food offered
stuffed	Stuffed myself with food
avoidhighcal	Tried to avoid foods with high calories
exerciseexhaust	Exercised to exhaustion
diureticsuse	Used diuretics to lose weight
fast	Skipped two meals in a row
autopilot	Ate on autopilot
overeat	Ate a large amount of food in a short period of time
EDE-Q	
restrict	Tried to limit the amount of food eaten for shape or weight concerns
fast	Gone for long periods of time without eating for shape or weight concerns
excludefood	Tried to exclude foods that you like for shape or weight concerns
foodrules	Tried to follow food rules for shape or weight concerns
emptystomac	Definite desire to have an empty stomach
flatstomach	Definite desire to have a flat stomach
foodconc	Thinking about food, eating, or calories made it difficult to concentrate
wsconc	Thinking about shape or weight made it difficult to concentrate
losecontrol	Definite fear of losing control overeating
feargain	Fear that you might gain weight
feelfat	Felt fat
desirelose	Strong desire to lose weight
overeat	Ate an unusually large amount of food
binge	Had a sense of losing control over your eating and ate an unusually large amount of food
vomit	Made yourself sick (vomit) for shape or weight concerns
laxatives	Taken laxatives for shape or weight concerns
compex	Exercised in a "driven" or "compulsive" way for shape or weight concerns
eatsecret	Ate in secret
guilty	Felt guilty for eating due to shape or weight concerns
otherseeeat	Concerned about other people seeing you eat
weightjudge	Weight influenced self-judgment
shapejudge	Shape influenced self-judgment
weighself	Upset if had to weigh once a week
weightdiss	Dissatisfied with weight
shapediss	Dissatisfied with shape
seeself	Discomfort seeing your own body
otherseebody	Discomfort with others seeing your body

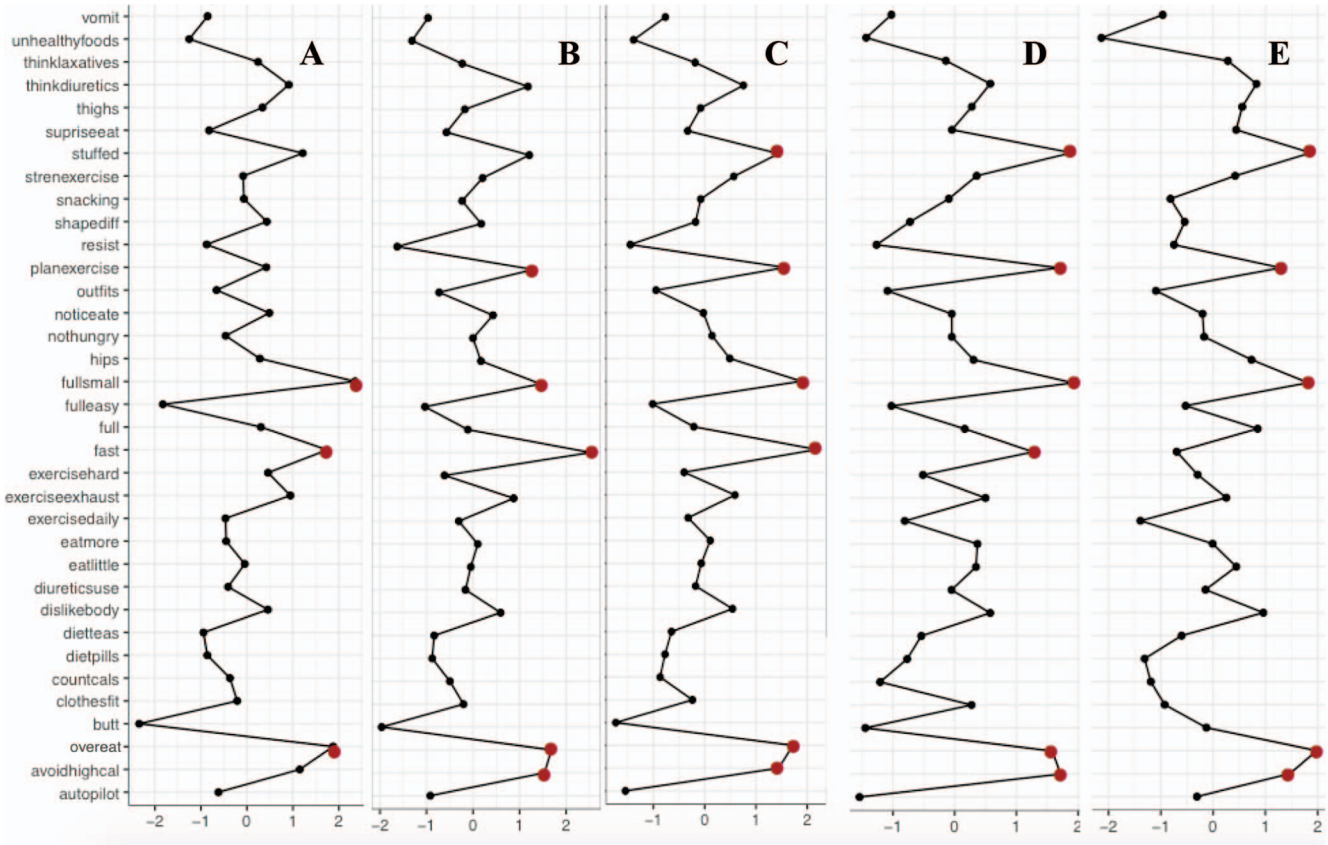

Figure 3. Centrality of EPSI symptoms for the (A) early adolescence, (B) late adolescence, (C) young adulthood, (D) early-middle adulthood, and (E) middle-late adulthood networks. Red (large) dots denote most central symptoms. See Table 2 for EPSI items corresponding to each node abbreviation. See the online article for the color version of this figure.

hood ($M = 0.17$, $p < .01$), but not late adolescence. The late adolescence network was significantly different from young adulthood ($M = 0.07$, $p < .05$), early-middle adulthood ($M = 0.10$, $p = .001$), and middle-late adulthood ($M = 0.16$, $p = .001$). The young adulthood network was significantly different than middle-late adulthood ($M = 0.14$, $p < .05$), but not early-middle adulthood. The early-middle adulthood network was not significantly different than middle-late adulthood.

Eight edges were significantly different ($p < .05$) between early adolescence and young adulthood, 20 edges significantly differed between early adolescence and early-middle adulthood, 23 edges significantly differed between early adolescence and middle-late adulthood, 12 edges significantly differed between late adolescence and young adulthood, 13 edges significantly differed between late adolescence and early-middle adulthood, 19 edges significantly differed between late adolescence and middle-late adulthood, and seven edges significantly differed between young adulthood and middle-late adulthood. See online supplemental materials for all significantly different edges and corresponding *E*-values.

Table 3
EPSI Central Symptoms

Early adolescence	Late adolescence	Young adulthood	Early-middle adulthood	Middle-late adulthood
Overeat (1.88)	Overeat (1.68)	Overeat (1.72)	Overeat (1.58)	Overeat (1.98)
Fullsmall (2.35)	Fullsmall (1.45)	Fullsmall (1.88)	Fullsmall (1.92)	Fullsmall (1.82)
	Avoidhighcal (1.54)	Avoidhighcal (1.44)	Avoidhighcal (1.72)	Avoidhighcal (1.47)
	Planexercise (1.29)	Planexercise (1.57)	Planexercise (1.69)	Planexercise (1.30)
Fast (1.75)	Fast (2.53)	Fast (2.19)	Fast (1.27)	
		Stuffed (1.44)	Stuffed (1.89)	Stuffed (1.87)

Note. Standardized strength centrality coefficients included in parentheses. All symptoms in the table were significantly more central than over 75% of other symptoms in the network. See Table 2 for EPSI items corresponding to each node abbreviation.

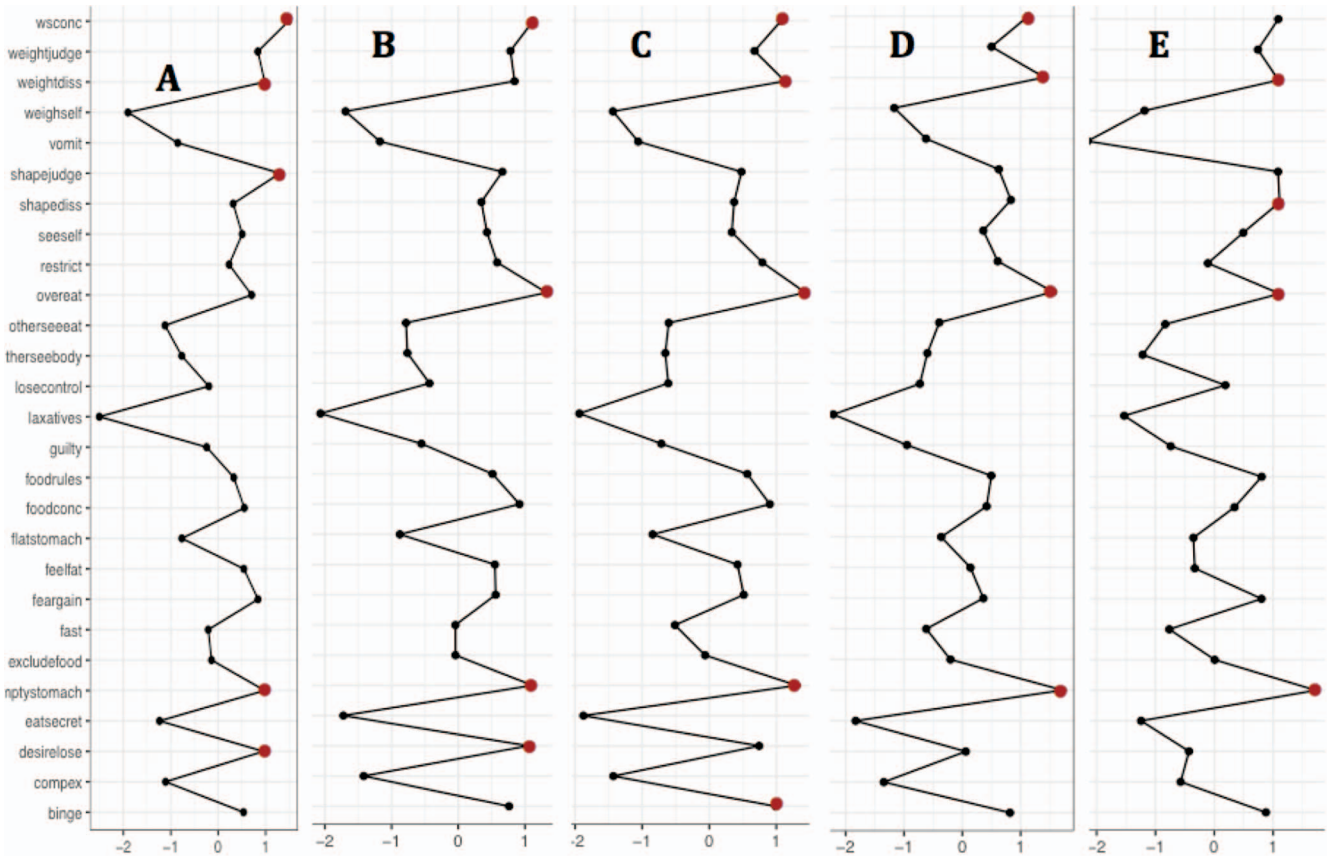

Figure 4. Centrality of EDE-Q symptoms for the (A) early adolescence, (B) late adolescence, (C) young adulthood, (D) early-middle adulthood, and (E) middle-late adulthood networks. Red (large) dots denote most central symptoms. See Table 2 for EDE-Q items corresponding to each abbreviation. See the online article for the color version of this figure.

The early adolescence network (global strength = 11.82) had significantly lower global strength than middle-late adulthood (global strength = 12.56; *GSI* = 0.74, $p < .05$). Late adolescence (global strength = 12.73) had significantly lower strength than young adulthood (global strength = 13.48; *GSI* = 0.75, $p < .01$) and early-middle adulthood (global strength = 13.61; *GSI* = 0.89, $p < .05$). There were no other significant differences in global strength among the EDE-Q networks ($p > .05$). See Table 5 for an overview of network differences across developmental stages.

ANOVA Across Developmental Stages

The results of the one-way ANOVAs indicated a significant main effect of group for body dissatisfaction, $F(4, 29{,}897) =$

Table 4
EDE-Q Central Symptoms

Early adolescence	Late adolescence	Young adulthood	Early-middle adulthood	Middle-late adulthood
Emptystomach* (.98)	Emptystomach** (1.11)	Emptystomach** (1.30)	Emptystomach** (1.72)	Emptystomach** (1.73)
Wsconc** (1.48)	Wsconc** (1.13)	Wsconc* (1.07)	Wsconc** (1.13)	
	Overeat* (1.32)	Overeat** (1.43)	Overeat** (1.56)	Overeat* (1.11)
Weightdiss* (.98)		Weightdiss** (1.13)	Weightdiss** (1.41)	Weightdiss* (1.09)
Desirelose* (.95)	Desirelose* (1.05)			
Shapejudge* (1.30)				
		Binge* (.99)		
				Shapediss* (1.11)

Note. Standardized strength centrality coefficients included in parentheses.
* Symptom is significantly more central than over 50% of other symptoms in the network. ** Symptom is significantly more central than over 75% of other symptoms in the network. See Table 2 for EDE-Q items corresponding to each node abbreviation.

Table 5
Network Comparison Tests

Developmental stage	Early adolescence		Late adolescence		Young adulthood		Early-middle adulthood		Middle-late adulthood	
	M	*GSI*	*M*	*GSI*	*M*	*GSI*	*M*	*GSI*	*M*	*GSI*
Early adolescence	—	—	**.11**	.92	**.15***	**1.67**	**.17***	**1.80**	**.18***	**.75***
Late adolescence	.12*	.81	—	—	**.07***	**.75***	**.10***	**.88***	**.17***	**.17**
Young adulthood	.52*	2.88	.52	2.07	—	—	**.06**	**.13**	**.14***	**.92**
Early-middle adulthood	.23*	1.60	.17*	.78	.49	1.29	—	—	.12	**1.05**
Middle-late adulthood	.29*	.33	.24*	.48	.51	2.55	.10*	1.26	—	—

Note. Bottom left (not bold) values represent network comparisons among EPSI networks. Upper right (bold) values represent network comparisons among EDE-Q networks. *M* = network invariance test statistic; *GSI* = global strength invariance test statistic.
* $p < .05$.

10.03, cognitive restraint, $F(4, 29{,}897) = 183.28$, binge eating, $F(4, 29{,}897) = 183.28$, purging, $F(4, 29{,}897) = 189.43$, restriction, $F(4, 29{,}897) = 700.49$, excessive exercise, $F(4, 29{,}897) = 215.31$, and global ED symptoms, $F(4, 32{,}214) = 107.64$, $p < .001$. Post hoc pairwise comparisons indicated that body dissatisfaction was highest in late adolescence, young adulthood, and early-middle adulthood. Purging was highest in late adolescence and young adulthood. Restriction, excessive exercise, cognitive restraint, and global ED symptoms were highest in early adolescence and significantly declined across development. Binge eating was lowest in early adolescence and significantly increased across development. See Table 6 for means and standard deviations for these measures across each developmental stage.

Discussion

This study utilizes NA to explore ED symptoms across fundamental developmental stages of adolescence and adulthood in a large sample of Recovery Record users. We hypothesized that central symptoms would be consistent across developmental stages but that the individual connections or pathways (edges) between symptoms may differ in strength. In support of our hypothesis, several symptoms emerged as central across all or most developmental stages. In partial support of our second hypothesis, there were significant differences in the network structure for all ED networks across both measures, but only significant differences in global strength among some of the EDE-Q networks. However, the results of the ANOVA contradicted these findings, as for most ED symptoms, excluding binge eating, symptom severity was highest for adolescence and young adulthood and declined later in adulthood, suggesting that the strength of the connections (but not the severity of symptoms) may increase across development. Overall, these network comparison results suggest that although many of the central symptoms remain consistent across developmental stages, the connections among symptoms significantly differ.

Central Symptoms

Several symptoms, including overeating and cognitions related to fullness, were central symptoms at every developmental stage. Several additional symptoms were central in four of the five networks, including symptoms related to food avoidance, overeating, and overvaluation of weight and shape. The high proportion of symptoms that were central across most or all developmental stages suggests that these ED symptoms may be central regardless of developmental stage. Thus, these symptoms may represent important targets for intervention for individuals with EDs across all developmental stages. Some symptoms were unique to one or two developmental stages, including additional symptoms related to overvaluation of weight and shape (e.g., dissatisfaction about one's shape; desire to lose weight). These symptoms may represent unique targets of intervention for the treatment of EDs in specific age populations.

Additionally, many of the central symptoms represent symptoms related to overvaluation of weight and shape, including concentration problems due to weight and shape, dissatisfaction

Table 6
Means and Standard Deviations of Study Measures Across Developmental Stages

Outcome	Early adolescence	Late adolescence	Young adulthood	Early-middle adulthood	Middle-late adulthood
EDE-Q global	**4.32 (1.07)**	**4.29 (1.07)**	**4.18 (1.11)**	**4.05 (1.10)**	**3.73 (1.14)**
EPSI body dissatisfaction	*20.70 (6.29)*	21.36 (5.67)	21.19 (5.88)	21.36 (6.05)	20.59 (6.40)
EPSI cognitive restraint	**8.26 (3.30)**	**8.11 (3.14)**	**7.84 (3.09)**	**7.20 (3.12)**	**6.44 (2.90)**
EPSI binge eating	**12.39 (9.04)**	**15.62 (9.37)**	**16.71 (9.37)**	**17.95 (9.02)**	**17.58 (8.16)**
EPSI purging	5.63 (5.94)	**6.58 (5.92)**	**6.10 (5.88)**	**5.08 (5.49)**	**3.08 (4.34)**
EPSI restriction	**13.98 (6.25)**	**12.62 (6.37)**	**10.75 (6.49)**	**8.22 (6.49)**	**6.91 (5.69)**
EPSI excessive exercise	**9.71 (5.81)**	**9.08 (5.65)**	**8.63 (5.82)**	**7.44 (5.67)**	**5.71 (4.82)**

Note. Values reported as *M* (*SD*). Italicized values were not significantly different ($p > .007$) than at least one other developmental stage. Bolded values denote stages significantly different than three or more other developmental stages.

about one's weight, dissatisfaction about one's shape, judgment about one's shape, and desire to lose weight. This finding is consistent with past conceptualizations of eating pathology using NA (DuBois et al., 2017; Forrest et al., 2018; Levinson et al., 2017; Wang et al., 2018) and supports the theory that overvaluation of weight and shape are core ED symptoms (Fairburn, 2008). A few symptoms that were highly central, including overeating and food avoidance, had not previously emerged as central in past studies. Thus, more research should test if these results replicate in other samples.

Differences Across Development

Despite the number of central symptoms that remained similar across developmental stages, the network comparison tests revealed significant differences in how symptoms were related across networks. The adolescent networks for both the EDE-Q and EPSI were significantly different from all the adulthood networks, suggesting that symptom relationships during adolescence significantly vary from adulthood. Additionally, the networks representing stages of adulthood were significantly different from each other for both measures, indicating that symptom relationships also are highly variable across the developmental stages of adulthood. The edge invariance tests supported these findings, as there were many significantly different edges across networks. All significantly different edges are included in online supplemental materials, as these edges represent pathways that may be differently important across developmental stages and provide insight into the clinical significance of network structure differences.

Overall, these findings suggest that important illness pathways may change across development, indicating that clinicians should expect fluctuations in the relationships among ED symptoms that occur with time and life experiences and that these changes may alter intervention targets. For example, fear of weight gain may be a common driving symptom across stages of development, but it may manifest differently over time (e.g., restriction may be more prevalent early on, but later shifts to judgment fears and isolation). Therefore, interventions may need to be tailored to address such changes.

In terms of global strength, only the EDE-Q networks exhibited significant differences, with trends indicating global strength increases for networks with older participants compared to younger participants. Higher global strength is theorized to be representative of greater severity (Pe et al., 2015; van Borkulo et al., 2015). However, comparisons in EDE-Q global scores and EPSI subscale scores across stages of development indicated that symptoms (based on total symptom scores) were more severe (i.e., higher) in the adolescent and young adult groups for all symptoms except binge eating. Bos et al. (2018) also found increased network connectivity corresponding with decreased severity, contrary to findings by van Borkulo et al. and Pe et al. As such, global strength may not necessarily correspond to greater overall severity of symptoms, but instead tighter connections between symptoms. The high interconnectivity of symptoms in the later developmental stages may be attributed to the longer average duration of illness of older individuals with EDs in our sample, which would likely indicate stronger, more reinforced pathways among symptoms, as suggested by Habit Formation Theory (Walsh, 2013).

Contrary to this finding, no significant differences in the global strength emerged across EPSI networks. This result was surprising, as the network comparison test detects even small differences. However, group comparisons indicated that some symptoms (e.g., binge eating) were stronger for older ages and other symptoms (e.g., restriction) were stronger in younger ages, so these opposing trends potentially "cancelled" each other out in the summation of strength across networks. It is also possible that this is an artifact of different measurement techniques that should be investigated in future research. Given the conflicting findings in the literature, future research should investigate how symptom interconnectivity (vs. symptom severity) may contribute to course of illness and outcomes.

Limitations

This study examines ED symptoms across developmental stages in the largest clinical ED sample used for NA to date, providing important insight into how ED symptomology may change across development. However, this study has limitations. One limitation is the missing diagnostic information in the data sets, which prevented us from using diagnosis-matched samples for each developmental stage. Recovery record only provides participant diagnostic information when the application is connected with a clinician, which was only applicable for 27.0–48.7% of the EPSI participants and 1.4–9.7% of the EDE-Q participants. Among the participants that did have ED diagnoses, there were significant differences in diagnoses across developmental stages. For example, in the EPSI network, the early adolescence group was primarily comprised of anorexia nervosa (55.3% of individuals with a clinician-provided diagnosis), and the middle-late adulthood group was primarily comprised of binge eating disorder (52.6% of individuals with a clinician-provided diagnosis). Due to these differences, it is possible that some of the network differences we found may be attributed to diagnostic differences as opposed to developmental stage. Future research should use diagnosis-matched samples to test if our findings replicate. However, despite differences in diagnoses across networks, many symptoms remained central across all networks. This finding supports the idea that despite differential diagnoses, EDs are transdiagnostic phenomena (Cooper & Dalle Grave, 2017; Lampard, Tasca, Balfour, & Bissada, 2013). Additionally, the ubiquity of core symptoms across diagnoses could contribute to the high diagnostic crossover in EDs (Castellini et al., 2011; Fichter & Quadflieg, 2007).

Further, because of the low prevalence of individuals above 46 that used the Recovery Record application, the middle-late adults network spans several decades (46–79 years of age). Thus, this study is unable to contribute to parsing out ED symptom differences across this large developmental category. Additional research should be conducted in middle and older adults, focused on identifying developmental differences in ED symptoms. Further, given that this is the first investigation of EDs across development from early adolescence to late adulthood, there are no established guidelines for distinct developmental periods in this population. Our categories are based on non-ED-specific developmental theories. Future research may refine these periods to ensure they reflect distinct stages of development for this population. Additionally, data were self-reported from the Recovery Record app and limited by self-awareness and self-report biases. Two sub-

scales of the EPSI, Muscle Building and Negative Attitudes Toward Obesity, were not measured in the Recovery Record app, so it is unknown how these constructs might vary across developmental stages.

One primary concern with NA is that there is currently no empirical method for selecting items for inclusion. As depicted by differences in central symptoms and connections across the EPSI and EDE-Q, item inclusion can critically impact interpretation of the network. For example, the EPSI, comprised of more behavioral ED symptoms, had more behavioral symptoms emerge as central, as compared to the EDE-Q. Future research should develop and validate empirical methods of selecting items for a network and developing measures designed to perform well in NA. Researchers have also expressed concerns with sole reliance on centrality indices to determine central symptoms (see Bringmann & Eronen, 2018; Hallquist, Wright, & Molenaar, 2019). However, in general, many researchers have suggested that central symptoms may serve as useful targets for future interventions (McNally, 2016; Rodebaugh et al., 2018), and growing empirical data shows that central symptoms predict important outcomes, specifically in EDs (Elliott et al., 2018; Olatunji et al., 2018). Finally, these networks were conducted at the group level, so findings indicate trends across developmental stages and may not be representative of symptom relationships for an individual over time.

Implications and Future Research

This study examines ED symptoms across developmental stages in a large clinical ED sample, which has broad implications for future research and treatment development for individuals with EDs. Significant network differences across stages suggest that ED research should be inclusive of individuals from all ages, especially older populations, who are typically left out of studies on treatment development (Forman & Davis, 2005). Additionally, differences across stages of development may impact treatment needs for subpopulations of EDs. For example, as symptom connections change in older populations, treatments may need to be adapted to focus on the strongest connections in order to disrupt the most salient illness pathways. Treatments for older individuals with EDs must also take into consideration the increased connectivity of symptoms, which may be contributing to the worse treatment outcomes for this population (Noordenbos et al., 2002; Norring & Sohlberg, 1993).

In addition, symptoms that are central to eating pathology across developmental stages, including items related to overeating, feelings of fullness, food avoidance, and overvaluation of weight and shape, are hypothesized to be good targets for intervention for individuals of all ages with EDs. Interventions that target these symptoms, including cognitive–behavioral and dialectical–behavior therapy interventions, such as thought challenging, exposure therapy, distress tolerance, and behavior chaining, are widely used and are among the most effective and empirically supported treatments for EDs (Fairburn, 2008; Linehan & Chen, 2005). Feelings of fullness can also be addressed using interoceptive exposures, which little research has investigated in EDs (Boettcher, Brake, & Barlow, 2016). Central symptoms that are unique to specific developmental stages may also be suggested targets for treatment for individuals with EDs that fall within that stage. However, it should be noted that group-level trends across development might not be reflective of the most important treatment targets for an individual. We hope that future research will explore similar questions within-persons. Overall, this study utilizes an emerging statistical approach to explore ED symptom differences across the life span, which future research will need to continue to address in order to develop more effective interventions for individuals of all ages who struggle with an ED.

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