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Stability and Variability of Edinburgh Postnatal Depression Scale Networks among Postpartum Women: Insights from the Japan Environment and Children's Study

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Running title: Edinburgh Postnatal Depression Scale Network Structures in Postpartum Women

Abstract

Background: This study aimed to clarify the network structure of the Edinburgh Postnatal Depression Scale (EPDS) in postpartum women using data from the Japan Environment and Children's Study (JECS), a large-scale nationwide birth cohort.

Methods: Network analysis was performed on EPDS data from 89,151 participants at 1 and 6 months postpartum. Gaussian graphical models (GGM) were employed to estimate the direct relationships between EPDS items; predictability measures were used to assess the degree of variance in each item that could be explained by the network. Subgroup analyses were conducted for groups with high (≥9) and low (<9) EPDS scores based on the Japanese cutoff for postpartum depression screening.

Results: The EPDS network structure was well-preserved from 1 month to 6 months postpartum. In both periods, "Sad" and "Anxious" demonstrated high centrality, playing key roles in the psychological network. Strong associations between "Hard to sleep" and "Self-harm" were observed in the high-score group at 1 month postpartum, but not at 6 months. Overall predictability was lower in the high-score group, suggesting greater involvement of external factors such as social support, economic conditions, and childcare burden.

Conclusions: This study provides the first insights into the EPDS network structure among postpartum women. Anxiety, sadness, and sleep disturbances emerged as key symptoms, underscoring the need for early intervention. Lower predictability in the high-score group suggests the influence of external factors, emphasizing the need for comprehensive support programs. Future research should consider other populations and time points, such as pregnancy and beyond 1 year postpartum.

Keywords: Edinburgh Postnatal Depression Scale (EPDS); Japan Environment and Children's Study (JECS); network analysis; postpartum women; postpartum depression.

1. Introduction

Postpartum depression (PPD) has adverse health impacts, including an increased risk of maternal suicide (Sit et al., 2015), attachment disorders with the infant (Murray et al., 1996), and delayed infant development (Deave et al., 2008). In his seminal work, Pitt (1968) reported a prevalence rate of 11% for PPD. More recently, a meta-analysis revealed PPD incidence among women with no prior history of depression to be approximately 12%, with a prevalence of approximately 17% (Shorey et al., 2018). In Japan, the period prevalence of PPD is reported to be 15.1% within the first month postpartum, 11.6% at 1–3 months, 11.5% at 3–6 months, and 11.5% at 6–12 months (Tokumitsu et al., 2020). Although differences in prevalence rates between countries exist (Hahn-Holbrook et al., 2017), PPD remains a widespread and consistent health issue globally.

Cox et al. (1987) developed the Edinburgh Postnatal Depression Scale (EPDS) as a screening tool for depressive symptoms during the postpartum period. The EPDS has been widely used in international clinical and research contexts and has been translated into over 60 languages (Cox, 2017). The scale consists of 10 items, and individuals scoring above a specified cutoff are considered at risk for depression, warranting further evaluation by a psychiatrist. Cox et al. (1987) initially designed the EPDS as a unidimensional scale to measure "depression." However, subsequent studies using factor analysis have suggested alternative factor structures for the EPDS, including two-factor models (e.g., "anxiety and depression" and "anhedonia" factors, or "anxiety" and "depression/anhedonia" factors) (Matthey, 2008; Zhong et al., 2014) and three-factor models (e.g., "anxiety," "depression," and "anhedonia") (Tuohy and McVey, 2008; Matsumura et al., 2020). Despite these findings, there is no consensus on the factor structure of the scale. Meanwhile, there have also been attempts to use subscales for screening

anxiety symptoms (Matthey, 2008; Phillips et al., 2009; Smith-Nielsen et al., 2021).

Psychological network analysis, introduced by Borsboom (2008), integrates multivariate statistics and network science. A network consists of two key elements: “nodes” and “edges.” Each node represents a variable (e.g., symptoms or personality traits), while each edge represents the partial correlation coefficient between two nodes after controlling for other variables in the model (Epskamp and Fried, 2018). In the visualized network graph, the distance between nodes reflects the strength of their relationships. Additionally, the thickness and color of the edges indicate the magnitude of these relationships. Examining the overall network layout helps to intuitively understand the interactions and associations among variables.

In the field of psychiatry, depression severity is typically assessed using total scores based on the number of symptoms. However, individual symptoms have distinct biological bases, impacts, and risk factors, highlighting the importance of analyzing symptoms individually and uncovering causal relationships as a means to develop effective treatments (Fried and Nesse, 2015). To our knowledge, thus far, only nine studies have involved network analyses focusing on perinatal mothers. For example, Phua et al. (2020) analyzed the networks of mothers at 26 weeks of pregnancy and 3 months postpartum using a combination of the EPDS, Beck Depression Inventory (BDI), and State-Trait Anxiety Inventory (STAI). Zhang et al. (2021) constructed a network using the 10 items of the EPDS for pregnant women and their husbands. Other studies have focused on women during pregnancy (Santos et al., 2017; Mazza et al., 2024), at 42 days postpartum (Wang et al., 2024), and at 3 months postpartum (Huang et al., 2024), but they all had small sample sizes. The remaining studies have focused on nutritional markers (Knox et al., 2023), perinatal risk factors (Speyer et al., 2021), and low birth weight (Harris et al., 2022). Thus, there is a dearth of research employing large-scale data for network analyses based on the 10 items of the EPDS at 1 month postpartum.

Psychological network analysis can be used to uncover the direct relationships between variables, potentially complementing existing exploratory analyses. Additionally, this approach allows for the identification of central variables—which could serve as key targets for intervention and treatment—within the network. Moreover, the visual representation of network structures facilitates a better understanding of scale composition and interactions among variables. In this study, we sought to clarify the network structure and relationships among the 10 items of the EPDS at both 1 and 6 months postpartum, utilizing data from a large-scale cohort study. Additionally, we examined whether the network structure differs based on the postpartum period and EPDS score levels.

2. Methods

2.1. Design and Participants

This study included mothers who took part in the Japan Environment and Children's Study (JECS), a large-scale nationwide birth cohort study currently supported by the Japanese government. The study aims to investigate various environmental factors and their effects on children's health and development. Participants were recruited between January 2011 and March 2014 from 15 Regional Centers across Japan, representing both rural and urban areas. JECS's data collection protocol and ethics approval, together with detailed descriptions of the cohort design, baseline characteristics, and supporting information on data validity, have been published previously (Kawamoto et al., 2014; Michikawa et al., 2018).

All procedures of the current study complied with the ethical standards of the relevant national and institutional committees on human experimentation and adhered to the 1975 Helsinki Declaration, as revised in 2008. The JECS protocol was reviewed and approved by the Ministry of the Environment's Institutional Review Board (approval number: 100910001) and

the Ethics Committees of all participating institutions. The current study was approved by the Institutional Review Board of Hokkaido University (approval number: 20-67). Written informed consent was obtained from all participants.

The dataset used for this research, jecs-an-20180131, was released in March 2018 and includes data from 103,062 pregnancies. To identify the number of unique mothers participating for the first time, 5,647 pregnancies were excluded due to duplicate registrations, 949 due to multiple births, and 3,676 due to miscarriages or stillbirths. Of the remaining 92,790 singleton pregnancies, 89,151 cases were included in the 1-month postpartum analysis, after excluding 3,639 cases missing EPDS data at this time point. The 6-month postpartum analysis included 83,402 cases, after excluding 5,749 cases with missing EPDS data at this time point (Figure S1).

2.2. Measurements

A self-administered questionnaire, including the Japanese version of the EPDS, was distributed at 1 and 6 months postpartum, as follows: during the 1-month health check-up at the Co-operating Health Care Provider where the birth took place—if not collected at the visit, it was returned by mail; 6 months after childbirth and collected by mail. The EPDS (Cox et al., 1987; Cox, 2019) is a 10-item self-report questionnaire scored on a Likert scale, assessing diverse aspects of mood and emotional distress: 1) laughing, 2) enjoyment, 3) self-blame, 4) anxiety, 5) fear, 6) coping difficulties, 7) sleep problems, 8) sadness, 9) crying, and 10) self-harm, with items 1 and 2 considered positive. Participants rated the degree of agreement with the given responses on a 4-point scale, with total scores ranging from 0 to 30. The cutoff for screening was defined as 12/13 in the original study (Cox et al., 1987), and this cutoff is still used in many countries now. The Japanese version of the EPDS was created using Okano et al.'s (1996) back-translation method; it was considered a valid translation, as the item values and response scales closely corresponded to the original version. It also demonstrated good internal

reliability (Cronbach's α = 0.78) and test-retest reliability (r = 0.92). The optimal cut-off for depression screening in Japan is set at 8/9 (with 75% sensitivity and 93% specificity). In this study, a score of 9 or higher was defined as indicative of a depressive state. Descriptive statistics (mean and standard deviation) for each EPDS item scored 0–3 were calculated, the Pearson correlation matrix was derived, and this matrix was compared with the Gaussian graphical model–estimated regularized partial correlation matrix via a Mantel test.

2.3. Network Analysis

2.3.1. Estimation of Network Structure

All analyses were conducted using R. The network structure was first computed using the "bootnet" package. Gaussian graphical models (GGMs) were estimated using the graphical lasso (LASSO) combined with the extended Bayesian information criterion (EBIC) for model selection. As the EPDS items are ordinal variables, the "cor_auto" function was used to omit ordinal variables, and polychoric correlations were calculated using "lavaan." Next, the network structure was estimated using the "estimatenetwork" function. Networks were plotted using "qgraph" (Epskamp et al., 2018). Nodes represent items; each pairwise relationship between items is defined as an edge. The thickness of an edge indicates the strength of the association. The color of the edge represents the direction of the association (e.g., blue wedges indicate positive associations, and red edges indicate negative associations). The Fruchterman–Reingold algorithm was used to construct the network. Nodes strongly and frequently connected to other nodes are depicted at the center of the network. Additionally, the variance of each node, accounted for by all other nodes in the network, was assessed using the "mgm" package (Haslbeck and Waldorp, 2018) to determine its predictability.

2.3.2. Centrality

Several measures of node centrality were calculated: strength (i.e., the sum of the absolute values of edge weights connected to a node), closeness (i.e., the average distance from a node to all other nodes within the network), and betweenness (i.e., the number of times a node lies on the shortest path between two other nodes).

2.3.3. Network Comparison

The network comparison test (NCT) was conducted to assess variations between networks based on the following criteria: (1) network structure (distribution of edge weights within each network and difference in the strength of each edge between two networks after controlling for multiple testing) and (2) global strength (total sum of the absolute values of all edge weights between networks).

2.3.4. Network Stability

Stability in network analysis refers to the consistency of network properties, such as edge weights and centrality measures, under resampling or perturbations. Assessing stability ensures that observed patterns are reliable and not artifacts of the specific dataset. Bootstrapping is commonly used to evaluate this by estimating confidence intervals, testing centrality reliability, and identifying structural variations. The bootstrap method of the "bootnet" package was used to assess the accuracy of the network. First, the accuracy of edge weights was estimated by calculating confidence intervals (CIs) using the non-parametric bootstrap method (Epskamp et al., 2018). Subsequently, 95% of CIs were calculated from new datasets created by randomly simulating the primary dataset. Second, the correlation stability coefficient (CS-C) was calculated using subset bootstraps to assess the stability of EI centrality. The CS-C represents the maximum percentage of the sample that can be removed for the correlation among the original centrality measures to reach at least 0.7 with 95% probability (Epskamp et al., 2018). Generally, the CS-C should not be <0.25, and preferably >0.5. Third, bootstrap difference tests

were conducted to evaluate differences in network appropriateness. Based on 95% CIs, this test determines whether two edge weights or two node centrality measures differ significantly from each other.

3. Results

3.1. Participant Characteristics

Data from 89,151 participants were analyzed. Participants' mean age was 30.8 ± 5.0 years; 50.2% of them were experiencing their first childbirth, 35.4% had an education of ≤12 years, and 36.8% had an annual household income of <4 million yen. Additionally, 4.5% of the participants were current smokers, and 10.0% reported current alcohol consumption. A history of psychiatric disorders was confirmed in 6.0% of the participants. Other participant demographics are presented in Table S1.

The distribution of participants' EPDS scores is shown in Figure S2. The frequency of participants scoring ≥9 on the EPDS, the Japanese cutoff for positive screening, was 14.4% at 1 month postpartum and 11.5% at 6 months postpartum. The mean scores and score distributions for each EPDS item are shown in Tables S2 and S3, respectively. Pearson correlation matrix and partial correlation matrix were presented in Table S4-S7. The matrix correlation between the Pearson correlation and the partial correlation matrices was r = 0.58 for the 1 month and increased to r = 0.87 for the 6 month, indicating substantially higher concordance at 6 months.

3.2. EPDS Network Analysis at 1 and 6 Months Postpartum

The network structures of the EPDS at 1 and 6 months postpartum are shown in Figure 1. Of the 45 possible edges, 36 were non-zero at 1 month, and 37 were non-zero at 6 months, confirming that the networks were properly formed at both time points.

As shown in Figure 2, the strength indices for 1 and 6 months postpartum exhibited

considerable overlap, indicating a strong similarity between the two time points. Among the nodes, E9 (Crying) demonstrated the highest strength, followed by E4 (Anxious), with this order remaining consistent across both time points. This suggests that these two nodes serve as central components of the network. Furthermore, the top six nodes were identical at both time points, comprising E1 (Laugh), E2 (Enjoy), E8 (Sad), and E10 (Self-harm), indicating their potential significance in the overall EPDS network structure.

Analysis of edge weights within the psychological network revealed that at 1 month postpartum, the edge weight of E1 (Laugh) - E2 (Enjoy) was the highest, indicating a strong association between items related to positive emotions. Items on emotions, such as E8 (Sad) - E9 (Crying), also played critical roles within the network (Table S8). A similar pattern was observed at 6 months postpartum, with the importance of items on emotions remaining consistent over time. However, there were no significant changes in the edge weights of E4 (Anxious) - E7 (Hard to sleep), and the overall network structure showed no major alterations over time (Table S9).

The network invariance test ($M = 0.072$, $P < 0.001$) confirmed statistically significant differences between the network structures at 1 and 6 months postpartum. Additionally, global strength value analysis indicated a significant decrease in overall network connectivity at 6 months compared to 1 month, with the calculated Δglobal strength = 0.0279 ($P = 0.004$).

Furthermore, we examined the predictability (R^2 value) of EPDS nodes at 1 and 6 months postpartum. The mean predictability was 0.799 and 0.810 at 1 and 6 months, respectively, indicating generally high values. However, for many nodes, predictability decreased at 6 months. Notably, E1 (Laugh) and E2 (Enjoy) exhibited high predictability at both time points, suggesting that a substantial proportion of their variance could be explained by other variables. Similarly, E7 (Hard-to-sleep), E9 (Crying), and E10 (Self-harm) also showed high

predictability. In contrast, E3 (Self-blame), E4 (Anxious), and E5 (Scared) displayed lower predictability, implying that factors outside the network may have influenced these nodes (Table S10).

Overall, the network structure of the EPDS at 1 and 6 months postpartum remained highly stable, with minimal changes observed.

3.3. EPDS Networks for Groups with High and Low EPDS Scores

The participants were divided into two groups based on the Japanese EPDS cutoff score of 9: low-score group (EPDS ≤8) and high-score group (EPDS ≥9).

3.3.1. One Month Postpartum

The network structures for the low-score and high-score groups at 1 month postpartum are shown in Figure 3. Of the 45 possible edges, 40 were non-zero in the low-score group, and 39 were non-zero in the high-score group, confirming that both networks were properly formed.

An examination of centrality indices revealed that the node with the highest strength was E9 (Crying). The second-highest node differed between groups: E4 (Anxious) in the low-score group and E2 (Enjoy) in the high-score group. Furthermore, E6 (Sad) exhibited consistently high strength across both groups. It is worth noting that the strength of E7 (Hard to sleep) was greater in the high-score group compared to the low-score group (Figure 4A).

Analysis of edge weights within the psychological network showed that in both groups, the edge weight of E1 (Laugh) - E2 (Enjoy) was the highest, indicating that items related to positive emotions played a central role in the network. Items on emotions, such as E8 (Sad) - E9 (Crying), also demonstrated high edge weights, confirming their significant roles within the overall network. However, in the high-score group, edge weight variability was greater, with a tendency for the importance of specific items on emotions to become concentrated. While E7 (Hard to sleep) was not central in the low-score group, it was strongly associated with items

related to emotions, such as E8 (Sad) and E9 (Crying), in the high-score group, emerging as a key node in the network. Additionally, in the high-score group, the edge weights associated with E10 (Self-harm) increased, with particularly strong connections observed between E10 and items on emotions (E8 (Sad) and E9 (Crying)) (Tables S11 and S12).

The network invariance test ($M = 0.1878$, $P < 0.001$) confirmed statistically significant differences in the network structure between the low- and high-score groups. Moreover, a comparison of global strength values revealed significantly lower overall connectivity in the high-score group compared to the low-score group, with the calculated Δglobal strength = 0.7645 ($P < 0.001$).

In the comparison of predictability between the low-score and high-score groups, the mean predictability in the high-score group was low at 0.69. Notably, E7 (Hard-to-sleep), E9 (Crying), and E10 (Self-harm) displayed lower predictability compared to the low-score group results, suggesting that these nodes were more strongly influenced by factors outside the network (Table S13).

3.3.2. Six Months Postpartum

The network structures for the low-score and high-score groups at 6 months postpartum are shown in Figure 5. Of the 45 possible edges, 38 were non-zero in the low-score group, and 41 were non-zero in the high-score group, confirming that both networks were properly formed.

An examination of centrality indices revealed differences in the node with the highest strength between the two groups. In the low-score group, E8 (Sad) had the highest centrality, while in the high-score group, E9 (Crying) had the highest centrality. This result indicates that in the high-score group, E9 (Crying) continued to be the most central node, consistent with findings at 1 month postpartum. Meanwhile, node E7 (Hard to sleep), which displayed higher strength in the high-score group at 1 month, no longer showed significant differences in strength

between the two groups at 6 months (Figure 4B).

Network analysis at 6 months postpartum revealed that in the low-score group, items related to positive emotions, such as E1 (Laugh) - E2 (Enjoy), had the highest edge weight, playing a central role in maintaining the stability of the network. Conversely, in the high-score group, items related to negative emotions, such as E8 (Sad) - E9 (Crying), had the highest edge weight. Additionally, items such as E3 (Self-blame) - E10 (Self-harm) were strongly associated with items on negative emotions. Notably, the edge weights involving E10 (Self-harm) increased, suggesting that self-harm may interact with negative emotions to heighten the instability of the network (Tables S14 and S15).

The network invariance test ($M = 0.2509$, $P < 0.001$) confirmed statistically significant differences in network structure between the low- and high-score groups. Furthermore, a comparison of global strength values showed that the overall connectivity in the high-score group was significantly lower than that in the low-score group, with the calculated Δglobal strength = 0.5659 ($P < 0.001$).

In the comparison of predictability between the low-score and high-score groups, the mean predictability in the high-score group was low at 0.67. Notably, E7 (Hard-to-sleep), E9 (Crying), and E10 (Self-harm) displayed lower predictability compared to the low-score group results, suggesting that these nodes were more strongly influenced by factors outside the EPDS network (Table S16).

3.3.3. Network Stability

We assessed the stability of all networks constructed in this study. The case-dropping bootstrap test revealed that the centrality strength (CS) coefficient was 0.75 for all networks, indicating a high level of stability. Additionally, the 95% CIs for edge weights obtained through bootstrap analysis were generally narrow, suggesting that the network structure was estimated

with high precision. Furthermore, a nonparametric bootstrap difference test confirmed significant differences in several edge weights (Figures S3–S8).

4. Discussion

Our findings indicate that the EPDS network structure remains highly stable from 1 to 6 months postpartum. Furthermore, we identified substantial differences in the EPDS network between individuals scoring above the screening cutoff for PPD and those scoring below it.

Although the EPDS was originally developed as a unidimensional scale, factor analyses have been conducted to examine its structural validity, adapt it culturally and linguistically, and improve its clinical applicability. Recent studies have frequently proposed a three-factor structure, comprising “anhedonia” (E1 and E2), “anxiety” (E3, E4, E5, and sometimes E6), and “depression” (E7, sometimes E8, E9, and sometimes E10) (Tuohy and McVey, 2008; Kubota et al., 2014; Kozinszky et al., 2017; Takehara et al., 2018; Matsumura et al., 2020; Saito et al., 2023); parentheses indicate items with varying factor assignments across studies. Factor analysis assumes latent variables (factors) to explain the covariance of observed data, modeling the hidden structure among items. In contrast, network analysis treats items as nodes and directly evaluates their interrelationships as edges, without assuming latent variables. It focuses on direct influences and dependencies among items. Despite their theoretical differences, comparing results from factor and network analyses can yield valuable insights. For example, our findings could be compared with Matsumura et al.’s (2020) results, who performed a factor analysis of EPDS using JECS data. This study used a factor loading threshold of 0.32. For instance, for E8 (Sad) at 1 month postpartum, the factor loadings for “anxiety” and “depression” were 0.36 and 0.43, respectively, signifying that it did not clearly belong to either factor, resulting in a cross-loading. In contrast, our network analysis revealed that E8 (Sad) had high

edge weights with both E4 (Anxious) and E9 (Crying). Furthermore, E8 (Sad) demonstrated high centrality within the overall network, indicating its importance as a key factor. Thus, network analysis provides new perspectives and interpretations of data.

Another interesting finding involves E6 (Hard to cope). Tuohy and colleagues reported that "Hard to cope" had cross-factor loadings between "depressive symptoms" and "anxiety symptoms." Other studies on the three-factor structure have also shown inconsistent latent factor assignments for "Hard to cope." In our network analysis, E6 (Hard to cope) was positioned far from other nodes, exhibited the lowest edge weights among the 10 items, and had the lowest centrality. These findings suggest that E6 has relatively weak interactions with other nodes in the network. The item "hard to cope" appears to have a more independent characteristic, with weaker direct connections to other specific emotional or behavioral factors such as "crying," "anxiety," or "sleep disturbances." Additionally, the subjective nature of "hard to cope" may lead to varied interpretations by individual respondents, weakening its associations with other items.

Recent studies have highlighted the persistence of depressive symptoms over an extended postpartum period. Data from Japanese populations have also indicated that the prevalence of PPD at 1 month and 1 year postpartum is similar. The network analysis at 1 and 6 months postpartum revealed no major changes in overall edge weight patterns or centrality indices. At 1 month postpartum, the edge weight between E1 (Laugh) and E2 (Enjoy) was the highest, while E9 (Crying) had the highest centrality strength. These trends were consistent at 6 months postpartum. Together, these findings suggest that the psychological network associated with PPD does not undergo significant short-term changes and maintains a relatively stable structure at least until 6 months postpartum.

At the same time, research has explored depressive symptoms and anxiety from pregnancy

through the early postpartum phase. Evidence suggests that depressive symptoms in early pregnancy predict higher anxiety levels in late pregnancy, while anxiety in late pregnancy predicts higher levels of depressive symptoms in the early postpartum period (Skouteris et al., 2009). Another study examining the course of generalized anxiety disorder and major depressive disorder (MDD) over 2 years postpartum found that generalized anxiety disorder is a risk factor for major depression, but not vice versa. Additionally, when the two co-occur, they are more likely to persist over the long term (Prenoveau et al., 2013). In our network analysis, E4 (Anxious) consistently demonstrated high centrality across all time points and EPDS score groups, highlighting its critical role in the network. In Figure 2, E3 (Self-blame) and E5 (Scared) are connected via E4 (Anxious). Interventions targeting anxiety may improve E3 and E5. Similarly, E8 (Sad) is strongly associated with other emotional and behavioral symptoms such as E9 (Crying) and E4 (Anxious), exerting a significant influence on the psychological network of postpartum women. Wang et al. (2024) also reported similar findings in their network analysis using the EPDS; Depression, Anxiety, and Stress Scales (DASS-21); and Maternal Postpartum Stress Scale (MPSS) with women at 42 days postpartum; their results indicated that the most central node was E8 (Sad), while E4 (Anxious) ranked fourth in centrality.

Regarding E10 (Self-harm), it was not strongly associated with specific nodes, rather showing moderate connections with many nodes. E10 (Self-harm) was closely linked to emotional factors, such as E8 (Sad) and E9 (Crying), suggesting that these emotions may contribute to self-destructive behaviors. Its association with E4 (Anxious) implies that excessive anxiety could act as a trigger for “self-harm.” Behavioral difficulties, as captured by E7 (Hard to sleep), may also act as stressors inducing self-harm. These findings indicate that self-harm is closely linked to multiple symptoms, suggesting that preventing the progression of PPD requires

a comprehensive intervention approach that considers the interactions among multiple symptoms, rather than focusing on a single symptom alone.

Next, we examined differences in network structures based on EPDS scores. However, it should be noted that the EPDS is not a diagnostic tool for PPD but rather a screening tool to identify those at risk. At 1 month postpartum, the centrality strength of E7 (Hard to sleep) was high in the high-score group, and E7 showed a strong association with E10 (Self-harm). This observation was unique to 1 month postpartum and disappeared by 6 months. A recently published network study comparing PPD and MDD during the puerperal period found that "insomnia" and "suicidal ideation" showed high centrality in PPD, while self-blame displayed high centrality in MDD (Tebeka et al., 2023). For women with high EPDS scores in the early postpartum period, interventions targeting sleep may be particularly important. Our findings suggest a strong association between sleep disturbances in the early postpartum period and self-harm. Specifically, in this study, a connection between E7 (Hard to sleep) and E10 (Self-harm) was observed only at 1 month postpartum, highlighting the critical role of sleep management for mental health during this period. Addressing sleep disturbances during the early postpartum phase may serve as an effective strategy for reducing the risk of self-harm. Possible interventions include sleep hygiene education to promote better sleep habits and, when necessary, the short-term use of pharmacological treatments.

This study reveals the results of both the GGM and the corresponding predictability measures. While the GGM illustrates the direct connections between variables, predictability indicates the extent to which a variable can be explained by other variables within the network. For example, if there is a strong edge between "stress" and "sleep," this reflects a direct relationship. However, if the predictability of "stress" is low, this suggests that factors outside the network may also influence stress. At both 1 and 6 months postpartum, the overall

predictability in the high-score group was lower. This result may indicate structural instability within the network, where psychological factors are diverse and dispersed, and no specific central items strongly predict other factors. Furthermore, this finding suggests the involvement of external factors, such as environmental influences (e.g., social support, economic conditions, childcare burden), which could significantly affect psychological states. It also implies that psychological states in the high-score group may be more complex. Furthermore, when comparing the two correlation measures, higher concordance was observed between the Pearson and partial correlation matrices at 6 months postpartum, indicating that the local and individual correlation structures were more closely aligned with the network structure at this point. In contrast, indirect associations became more dominant at 1 month postpartum.

Regarding the strengths of this study, using a large sample enabled highly stable edge estimation and detection of even weak correlations and edges. Additionally, subgroup analyses were performed thoroughly, and the robustness of the results was confirmed through bootstrapping. Furthermore, given that various factors affect the onset of PPD, a key strength of this study is its focused investigation of the network structure within the EPDS alone. This approach allows a detailed examination of the relationships between depressive symptoms without the influence of external variables.

However, there are some limitations to this study. First, data on EPDS scores before 1 month postpartum and after 6 months postpartum were unavailable. Second, the data analyzed were from participants in the JECS, making it difficult to generalize the findings to other populations.

In conclusion, this study is the first to clarify the network structure of the EPDS in postpartum women, also demonstrating that the structure remains stable from 1 to 6 months postpartum. Notably, in the high-score group, strong associations between insomnia and self-harm were observed, with E8 (Sad) and E4 (Anxious) playing central roles. Early intervention

targeting these items is considered crucial for preventing PPD. Additionally, the predictability results suggest that psychological factors in the high-score group are more diverse and that external factors, such as social support and economic conditions, may have a significant impact. Future efforts should focus on developing comprehensive support programs that account for these external factors.

Glossary

Anhedonia: A condition characterized by the inability to experience pleasure from activities usually found enjoyable, such as social interactions, hobbies, or food.

Bootstrapping: A resampling method used to estimate the stability and accuracy of network models by repeatedly drawing samples from the original dataset with replacement.

Centrality Measures: Indicators used in network analysis to determine the importance of a node within a network. Common measures include strength, closeness, and betweenness.

Correlation Stability Coefficient (CS-C): A metric that quantifies the stability of centrality measures in network analysis, indicating the maximum proportion of cases that can be removed while maintaining a strong correlation with the original results.

Edge: A connection between two nodes in a network, representing a statistical relationship such as a correlation or partial correlation between variables.

Gaussian Graphical Model (GGM): A statistical model that represents the conditional independence structure among variables using a network of partial correlations.

LASSO (Least Absolute Shrinkage and Selection Operator): A regularization method used in network analysis to enhance model sparsity by reducing weak edges.

Network Analysis: A statistical approach that represents psychological symptoms as interconnected nodes, analyzing their relationships rather than relying on traditional total scores.

Network Comparison Test (NCT): A statistical method used to compare differences between two networks in terms of their structure and connectivity.

Node: A fundamental unit in a network representing an individual variable, such as a symptom in psychological network analysis.

Predictability: A measure indicating how much variance in a given node can be explained by its direct connections within a network.

Stability in Network Analysis: The consistency of network properties (e.g., edge weights, centrality) under resampling or data perturbations, ensuring that findings are not artifacts of specific datasets.

CRediT Authorship Contribution Statement

Yasuhiko Ebina: Writing – original draft, methodology, formal analysis, conceptualization, visualization, writing – review and editing. Sachiko Ito: Conceptualization, writing – review and editing. Takeshi Yamaguchi: Conceptualization, writing – review and editing. Hiroyoshi Iwata: Conceptualization, project administration, writing – review and editing. Reiko Kishi: Writing – review and editing, supervision.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

In the course of preparing this work, the authors utilized ChatGPT to improve the coherence and readability of the manuscript. Following the use of this tool, the authors carefully reviewed and revised the content as necessary and assume full responsibility for the final version of the publication.

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Declaration of Interests

None

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Appendix

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Data Availability

Data are unsuitable for public deposition due to ethical restrictions and legal framework of Japan. It is prohibited by the Act on the Protection of Personal Information (Act No. 57 of 30 May 2003, amendment on 9 September 2015) to publicly deposit the data containing personal information. Ethical Guidelines for Medical and Health Research Involving Human Subjects enforced by the Japan Ministry of Education, Culture, Sports, Science and Technology and the Ministry of Health, Labour and Welfare also restricts the open sharing of the epidemiologic data. All inquiries about access to data should be sent to: jecs-en@nies.go.jp. The person responsible for handling enquiries sent to this e-mail address is Dr Shoji F. Nakayama, JECS Programme Office, National Institute for Environmental Studies.

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Figure 1

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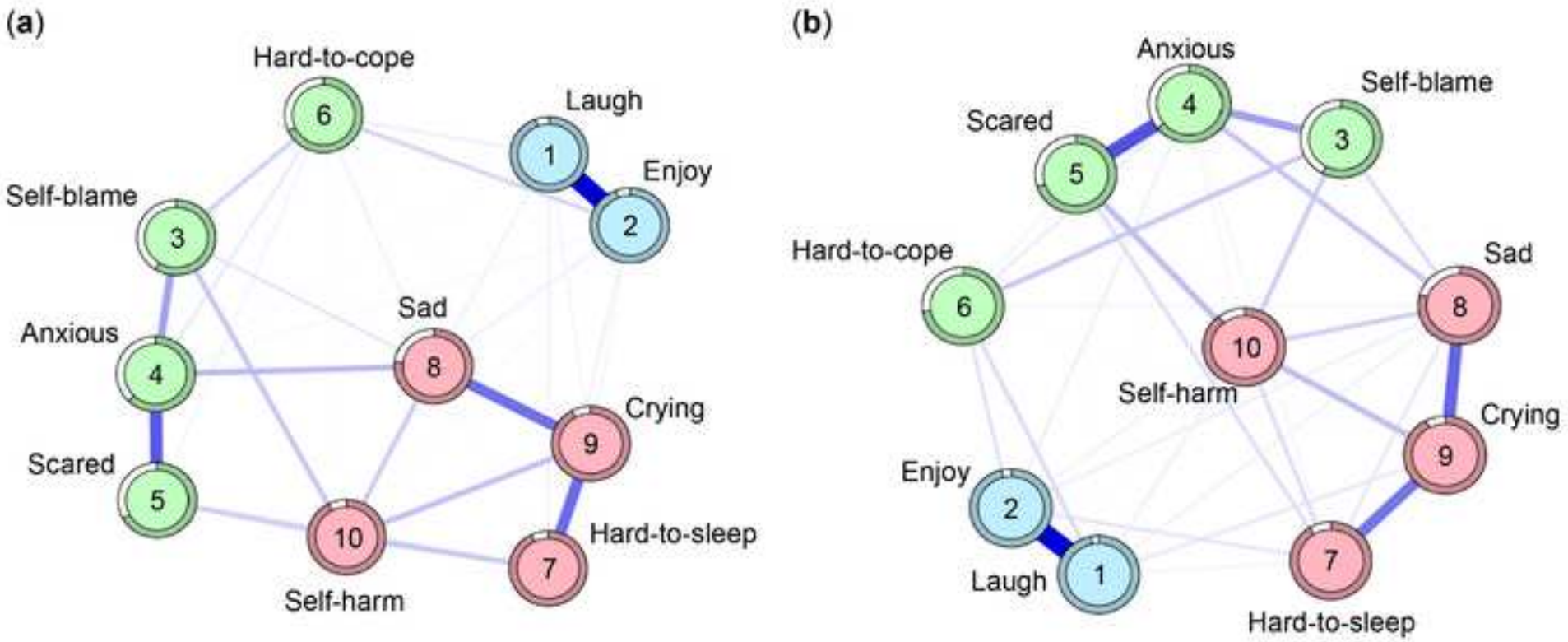


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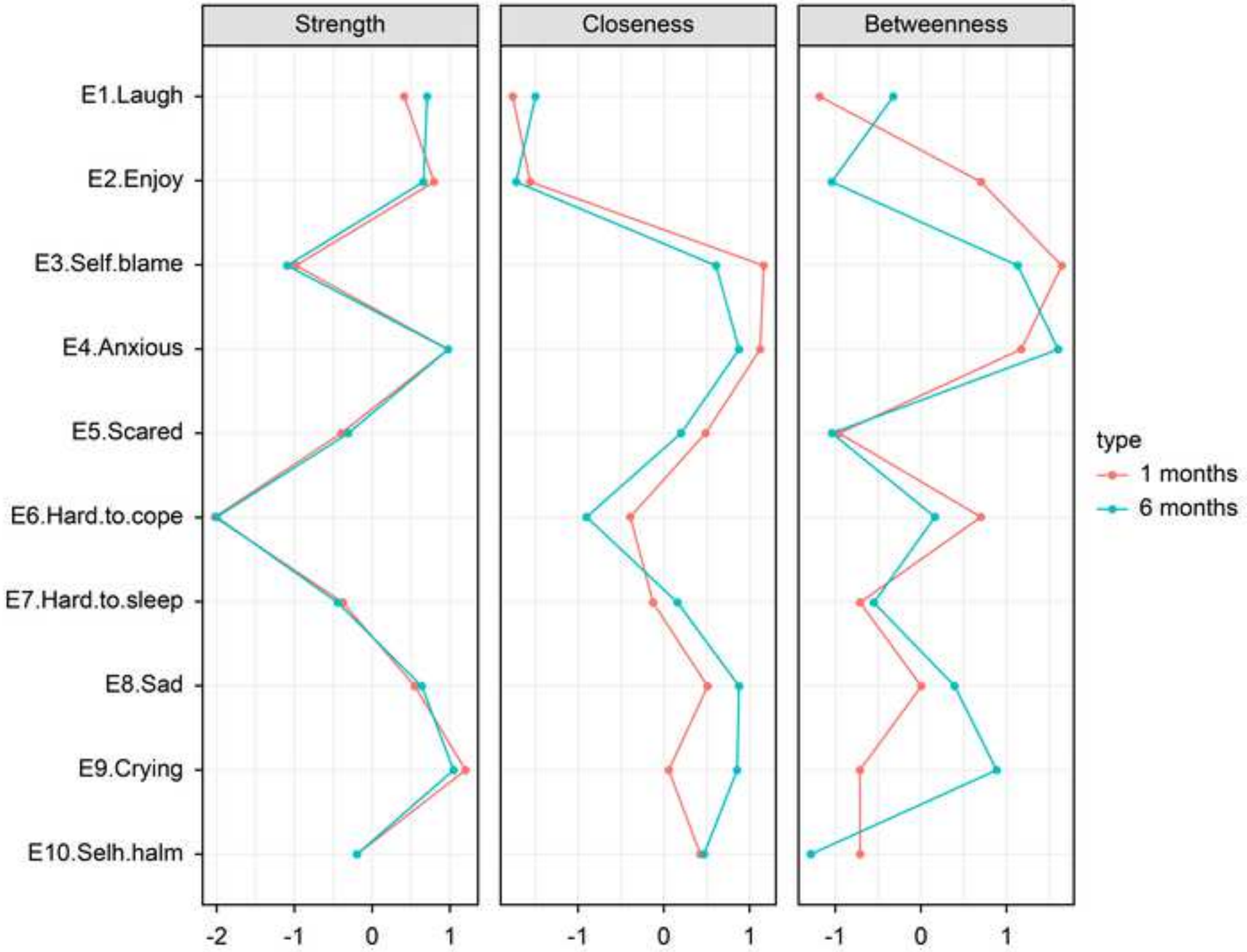


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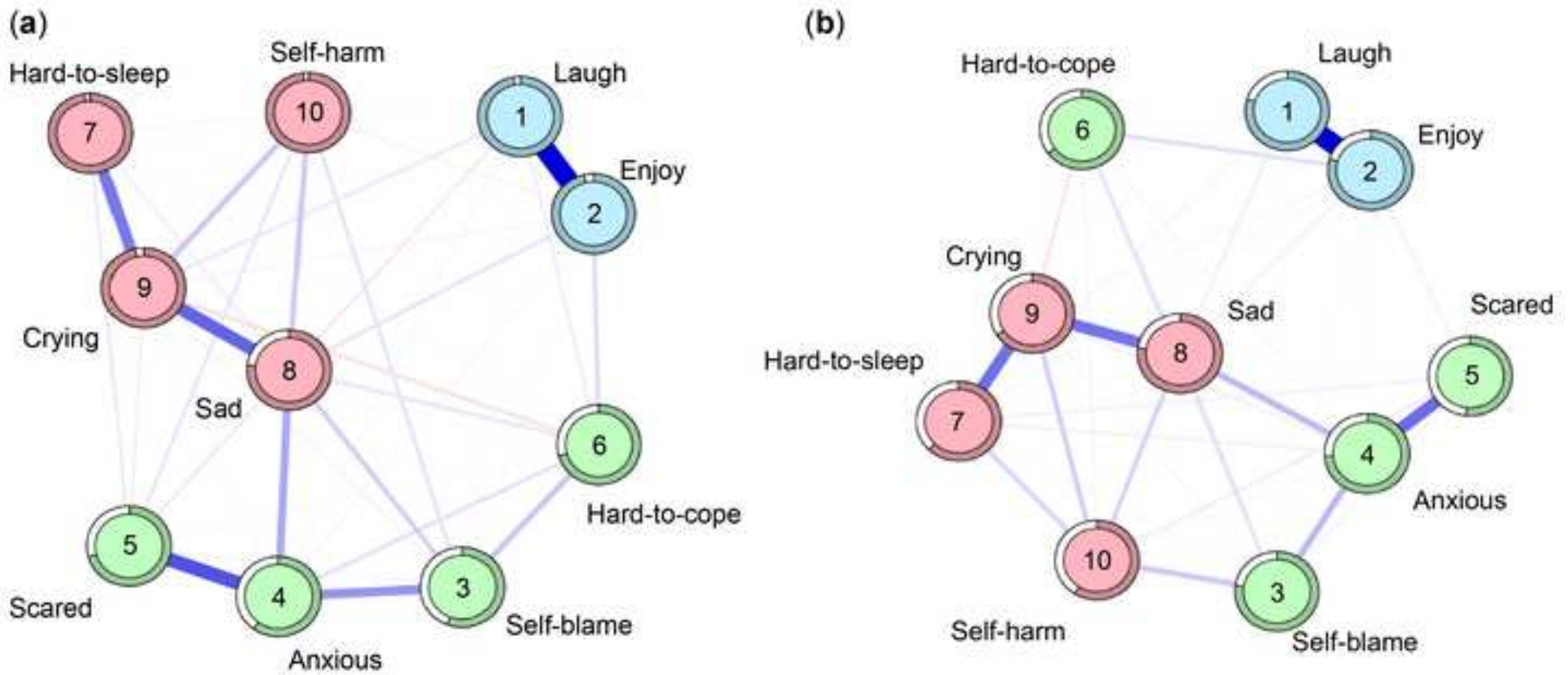


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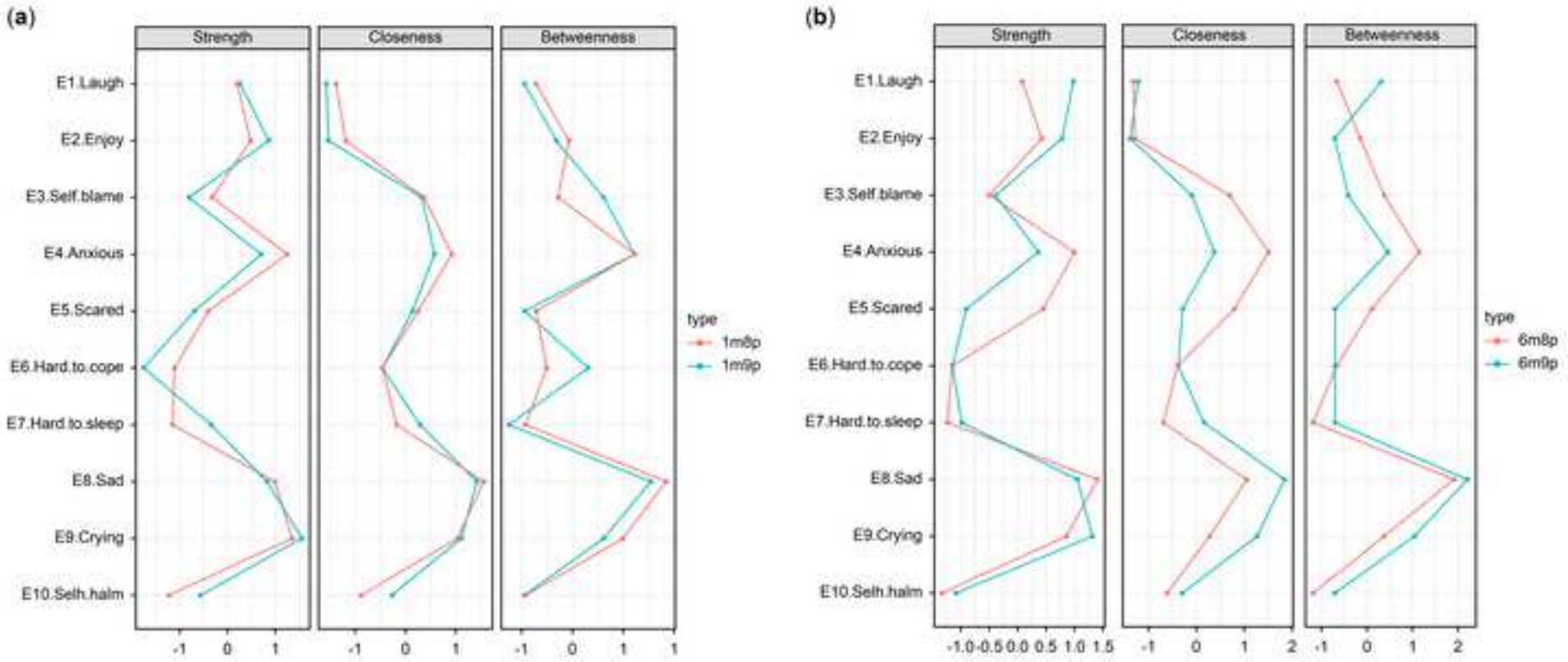
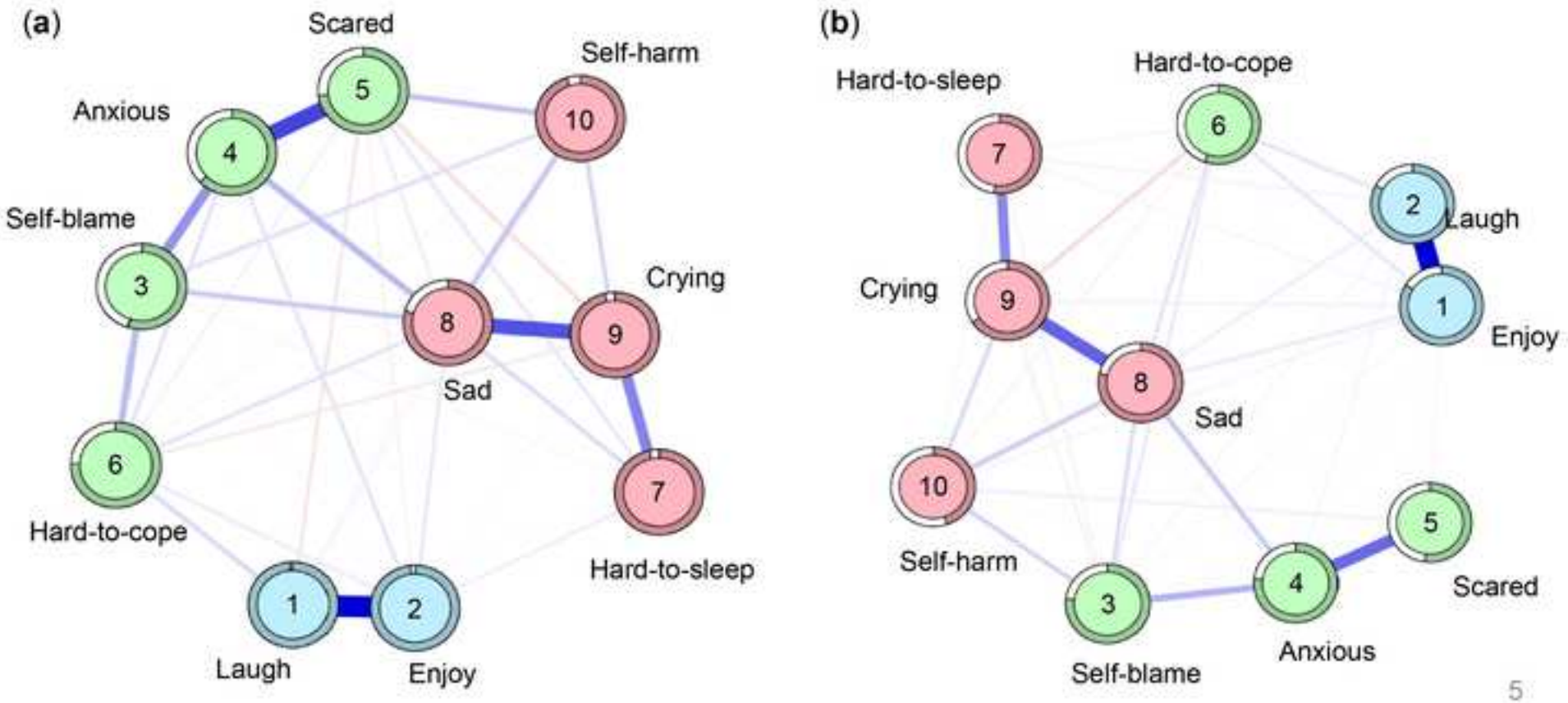


Figure 5

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Figure captions

Figure 1: Estimated network model for the Edinburgh Postnatal Depression Scale (EPDS)

A: EPDS at 1 month postpartum (n=89,151) B: EPDS at 6 months postpartum (n=83,402)

In this network diagram, red lines signify a negative correlation, blue lines represent a positive correlation, and bolder lines denote stronger correlations. The rings around the nodes represent the predictability of each node. For convenience, the node colors are assigned as follows: blue for anhedonia, green for anxiety, and red for depression.

Figure 2: Comparison of centrality indices in the estimated network model of the Edinburgh Postnatal Depression Scale (EPDS) at 1 and 6 months postpartum

Figure 3: Estimated network model for the Edinburgh Postnatal Depression Scale (EPDS)

A: EPDS ≤8 points at 1 month postpartum (n=76,333) B: EPDS = ≥9 points at 1 month postpartum (n=12,818)

Figure 4: Comparison of centrality indices in the Edinburgh Postnatal Depression Scale (EPDS) network model for scores ≥9 and ≤8

A: EPDS at 1 month postpartum B: EPDS at 6 months postpartum

Figure 5: Estimated network model for the Edinburgh Postnatal Depression Scale (EPDS)

A: EPDS ≤8 points at 6 months postpartum (n=73,803) B: EPDS ≥9 points at 6 months postpartum (n=9,599)