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ORIGINAL PAPER

The Impact of Compassion Meditation Training on Psychological Variables: a Network Perspective

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Abstract

Objectives We aimed to examine how a standardized compassion meditation program would induce changes in the patterns of interactions among psychological variables.

Methods We conducted network analyses on psychological variables before and after 96 participants completed an 8-week Compassion Cultivation Training (CCT) program.

Results After the CCT program, self-compassion variables increased their importance and influence in the network (i.e., centrality), whereas psychopathology and negative functioning variables (e.g., stress, anxiety, depression, and rumination) decreased their centrality. More importantly, self-compassion increased its associations with other adaptive variables (e.g., emotional reappraisal and mindfulness) after the program. Also, self-compassion, non-attachment, and decentering were the nodes connecting different sub-networks (i.e., bridge nodes), decoupling psychopathological variables (i.e., psychological distress and rumination) from the rest of the network. The variance of compassion, mindfulness, and well-being was mostly explained by other nodes in the network (i.e., predictability), whereas psychopathology-related constructs diminished in their predictability after the program.

Conclusions These results highlight the role of self-compassion and other adaptive variables as the key mechanisms through which compassion meditation may produce its effects.

Trial Registration ClinicalTrial.org (NCT03920241)

Keywords Compassion · Meditation · Compassion Cultivation Training · CCT · Mechanisms · Network analysis

Compassion has long been a fundamental value in Eastern contemplative traditions, yet only in the last two decades has it received scientific interest (Gilbert 2019; Kim et al. 2020a). Using varying definitions of compassion, researchers have studied compassion from diverse perspectives addressing its emotional component (Goetz et al. 2010), its contribution to the concept of the self (Neff 2003b), and its motivational role (Gilbert 2019), among others. In an attempt to integrate these perspectives, Strauss et al. (2016) identified several common themes: (1) awareness (i.e., to recognize the suffering in oneself and others); (2) universality (i.e., to understand that all human beings suffer); (3) empathy (i.e., emotional resonance with the person who is suffering, connecting with their distress); (4) acceptance (i.e., being able to tolerate one's uncomfortable feelings and thoughts in response to suffering); and (5) motivation (i.e., to being motivated to act to alleviate the suffering). This five-factor structure has received preliminary empirical support (Gu et al. 2017).

Preliminary evidence highlights the potential benefit of compassion on a wide range of outcomes, including increases in brain plasticity (Klimecki et al. 2014), neural responses to experienced or observed suffering (Kim et al. 2020a), lower physiological reactivity to stress (Cosley et al. 2010), prosocial behavior (Condon et al. 2013; Luberto et al. 2018), social connectedness (Crocker and Canevello 2008), psychopathology (MacBeth and Gumley 2012), and well-being (Neff et al. 2007), among others.

Despite the growing interest in meditation effects, the scope of scientific research has been focused on mindfulness

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practice, and other forms of meditation have not received the scientific attention they deserve (Davidson and Dahl 2018). A contemporary conceptualization distinguishes between three families of meditation practices (Dahl et al. 2015): (a) attentional family: practices used to train the self-regulation of attention and the interoceptive awareness, which would include the practice of mindfulness; (b) constructive family: practices used to cultivate psychological well-being by developing prosocial qualities and socio-emotional skills, such as compassion, kindness, equanimity, and joy; and (c) deconstructive family: practices used to cultivate socio-cognitive skills by developing self-inquiry, self-knowledge, and wisdom.

In regard to interventions directly or indirectly aimed at enhancing compassion, mindfulness-based interventions (MBI) have been widely disseminated and scientifically assessed in recent years (Goldberg et al. 2018). In MBI, compassion is taught implicitly as an attitudinal foundation of mindfulness and is modeled by the instructors' behaviors and attitudes (Brito-Pons et al. 2018). compassion-based interventions (CBIs) have also been developed, aimed at teaching compassion explicitly within a meditation framework (Kirby 2017). Most CBIs follow highly structured formats, are time-limited, and include assessment tools to verify participants' changes. These features render them suitable for scientific evaluation. The meta-analysis conducted by Kirby et al. (2017) on compassion interventions found moderate between-group differences on self-compassion, mindfulness, psychological distress (i.e., depression and anxiety), and well-being, even in those randomized controlled trials (RCTs) where an active control comparison group was included.

Compassion Cultivation Training (CCT) is an 8-week secular program designed to enhance compassion (Goldin and Jazaieri 2017). Several studies, including RCTs, have found that CCT significantly promotes beneficial changes in participants from the general population such as: (1) increasing self-compassion, compassion for others, and being the object of compassion for others (Jazaieri et al. 2013), and decreasing fear of compassion for self (Goldin and Jazaieri 2017); (2) reducing stress, anxiety, and depression (Brito-Pons et al. 2018; Jazaieri et al. 2018); (3) increasing positive affect and decreasing negative affect (Jazaieri et al. 2014); (4) enhancing adaptive emotional regulation strategies such as cognitive reappraisal and reductions in emotion suppression (Jazaieri et al. 2014, 2018); (5) enhancing adaptive cognitive regulation processes (i.e., increasing mindfulness and reducing mind wandering, worry, and rumination) (Jazaieri et al. 2014, 2015); (6) increasing well-being levels (Brito-Pons et al. 2018; Jazaieri et al. 2014); and (7) promotion of caring behaviors and empathic concern (Jazaieri et al. 2015). Furthermore, CCT appears beneficial for certain populations, such as adults experiencing chronic pain (Chapin et al. 2014) and healthcare workers (Scarlet et al. 2017). Given the similarities between standardized mindfulness and compassion programs, Brito-Pons et al. (2018) analyzed the effects of CCT in comparison with a Mindfulness-Based Stress Reduction (MBSR) group. They found that both CCT and MBSR enhanced well-being, mindfulness, and compassion skills. However, the CCT intervention had a greater impact than MBSR on compassionate skills (i.e., self-compassion, empathic concern, and common humanity).

Given the growing interest in comparing meditation-based interventions, it is scientifically relevant to analyze the mechanisms of actions through which different interventions produce their effects. The increasing number of studies analyzing the mechanisms of mindfulness (Gu et al. 2015; Hölzel et al. 2011; Tang et al. 2015) contrasts with the relatively few studies on mechanisms of compassion interventions (Gu et al. 2017). Despite the general agreement on the need to increase research on the mechanisms of change in psychological interventions (Kazdin 2009; Nielsen et al. 2018), statistical approaches to analyze those mechanisms, like traditional mediation analyses, may fail to uncover their complex dynamics (Hofmann et al. 2020). Alternatively, network analytic approaches (e.g., Borsboom and Cramer 2013) may better characterize the complex interactions between outcomes and mechanisms involved in psychological interventions. However, with few exceptions (e.g., Papini et al. 2020), network analysis remains underused in the study of intervention-induced mechanisms of change.

In an innovative approach aimed at revealing the mechanisms of MBIs, Roca et al. (2019) used network analysis to explore whether a MBSR program can change the patterns of relations among psychological constructs. The authors found significant changes in the network topology after the MBSR program, resulting in a reorganization of the relations among the different psychological constructs. Network analysis showed that self-compassion constructs behave similarly to most mindfulness measures, becoming strongly connected with well-being after the intervention. Furthermore, adaptive emotional regulation strategies increased their connections with mindfulness and well-being measures after the MBSR. Corresponding more closely with theoretical models, community analysis revealed the following clusters: (1) a cognitively oriented cluster of mindfulness nodes, (2) an emotionally oriented one consisting of mindfulness and self-compassion nodes, (3) another comprising distress and cognitive-emotional dysregulation nodes, (4) one comprising well-being nodes, and (5) one consisting of nodes signifying compassion for others. Furthermore, they used this study as a proof-of-concept of the *psychonectome* (i.e., the idea that psychological functioning depends upon a complex dynamic

ensemble of dependencies among different psychological constructs) and its utility to analyze patterns of change after interventions.

In the last decade, network analysis has been used as an innovative framework to understand psychopathology (Borsboom and Cramer 2013; McNally 2016). In contrast to both categorical and dimensional traditional diagnostic models, the network approach does not conceptualize the symptoms as reflective of underlying disorders. Rather, it views episodes of mental disorder as emergent (not "underlying") phenomena arising from interactions among their constitutive symptoms (Borsboom and Cramer 2013). In network analysis, the focus is transferred from the changes in individual variables to the relation between them, which can be especially useful in illuminating structural psychological changes after intervention programs. Psychological variables are represented by nodes (i.e., circles) and the relationship between them is represented by edges (i.e., lines connecting pairs of nodes). The edge weight represents the probability of co-activation between two nodes.

In the present study, we computed weighted, undirected networks comprising edges depicting (regularized) partial correlations between pairs of variables representing psychological constructs relevant to compassion meditation. We also computed node centrality metrics for these variables that estimate their connectedness and potential causal influence within the network. We aimed to examine how a standardized compassion program, such as CCT, would induce changes in the patterns of interactions between different psychological constructs. We had five hypotheses. First, we predicted that CCT would result in significant increases in compassion, mindfulness, well-being, and adaptive cognitive-emotional control, and significant reductions in psychological distress and non-adaptive cognitive-emotional control measures. Second, we predicted that CCT would promote a topological network reorganization such that compassion variables would increase their connections with mindfulness and adaptive emotional-cognitive regulation measures after the program. Third, we hypothesized that the centrality values for nodes signifying compassion, mindfulness, and well-being would increase following CCT, whereas those for distress and cognitive-emotional dysregulation would decline. Fourth, we expected that compassion, mindfulness, and well-being would be the more predictable nodes (i.e., the nodes for which more variance could be predicted by other nodes in the network). Fifth, we predicted that CCT would change the clustering of the measured constructs towards more meaningful communities, corresponding more closely with the five theoretical domains of constructs selected for this study according to theoretical models of compassion (Goldin and Jazaieri 2017; Gu et al. 2017).

Method

Participants

Between April and December 2017, 106 participants enrolled in a standardized 8-week CCT at a university-associated research center specializing in mindfulness and compassion-based interventions. The inclusion criteria for the CCT were as follows: (1) 18 years of age or more, and (2) not having any current serious psychological disorder or substance use.

Statistical analyses were conducted only for data from participants who completed pre-assessment and attended a minimum of 6 sessions (i.e., 75% of the program). A description of the participation flow diagram is presented in Fig. 1. After applying all exclusion criteria, data from a total of 96 individuals were included in all analyses. Their mean age was 47.78 (SD = 9.80), 75% were women, 90.6% had a university education, 42.7% were married, 79.2% were employed, 11.5% had a physical illness, and 85.4% had previous meditation experience (i.e., mean of 4.81 years [SD = 5.58]).

Procedures

The study followed a pre-/post-design. Participants were invited to take part in the study when they registered on the official website offering the compassion program. Those who agreed to participate were administered a brief online screening questionnaire on demographics and inclusion criteria after providing written informed consent. After enrolling, participants completed an online assessment during the week before starting the program (i.e., pre-assessment) and during the week after its completion (post-assessment). The online assessment consisted of questionnaires administered via Qualtrics software, which lasted approximately 45 min. When necessary, Qualtrics reminders were scheduled for those participants who had not completed the questionnaires. After completing the post-assessment, participants were debriefed and received an individualized report of their questionnaire scores. The research was approved by the university ethics committee prior to participant recruitment (Ref 2016/17-016) and was registered at ClinicalTrial.org (NCT03920241).

Compassion Cultivation Training (CCT)

The CCT was delivered through a university-associated center specializing in mindfulness and compassion-based interventions. The program was implemented by two highly experienced instructors, certified by the Center for Compassion and Altruism Research and Education (http://ccare.stanford.edu/) at Stanford University, with a combined teaching experience of over fifty CCTs in the last five years. Program adherence was supported through regular group supervision meetings.

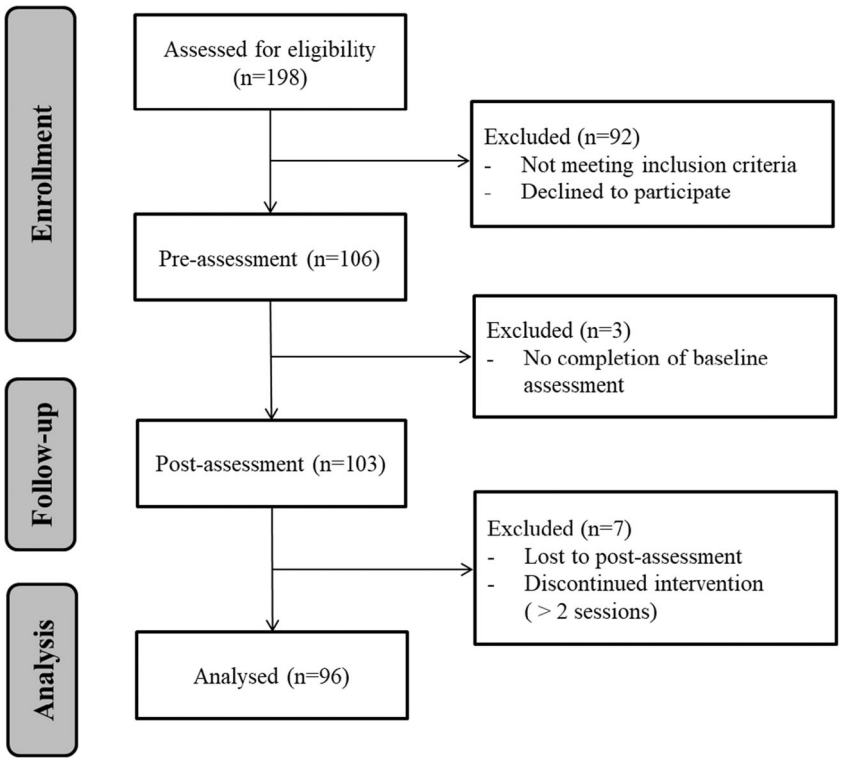

Fig. 1 Participation flow diagram

Furthermore, each participant received a set of pre-recorded audio files to guide the daily practices and a workbook.

The CCT is an 8-week standardized program (Brito-Pons et al. 2018; Goldin and Jazaieri 2017) consisting of 2.5 h of face-to-face session per week and 30 min of daily home formal and informal practices. Training was conducted in groups of 20–30 participants. The CCT consists of six sequential steps addressing the different components of compassion (see Table 1): (1) settling the mind and learning how to focus it; (2) practicing loving-kindness and compassion for a loved one; (3) practicing loving-kindness and compassion for oneself; (4) compassion toward others, embracing shared common humanity, and developing appreciation of others; (5) compassion toward others including all beings; and (6) active compassion practices (*tonglen*) involving explicit evocation of the altruistic wish to do something about others' suffering. Finally, participants learn an integrative compassion practice combining the six essential elements into an integrative compassion meditation practice.

Measures

The online assessment included questionnaires evaluating five domains considered central in psychological theories of meditation and compassion (Goldin and Jazaieri 2017; Malinowski 2013): mindfulness, compassion, psychological well-being, psychological distress, and emotional-cognitive control. Table 2 shows a brief description of the measures as well as the internal consistency scores (i.e., Cronbach's alpha) found in this sample.

Data Analysis

Network analyses were carried out with R version 3.3.1, whereas data pre-processing, missing value analysis, imputation methods, and univariate statistical test (i.e., *t* tests) were conducted with SPSS v.25. Following Hair et al.'s (2014) recommendations to treat missing data, maximum likelihood (ML) estimation was performed via expectation-maximization (EM) imputation. There were 13.4% of overall missing values and none of the measures exceeded the recommended limits for missing values. A Little MCAR test ($\chi^2_{(1674)} = 356.45$, $p > .05$) showed that the pattern of missing data was random and suitable for imputation. Finally, a sensitivity analysis comparing the completers to the estimated values was carried out, concluding that the ML estimation would not lead to biased estimations.

Network analysis was conducted following standard guidelines and R packages (Fried et al. 2018; Jones et al. 2018—see technical details in the Supplementary Materials file) with the aim of (1) analyzing the pre-/post-changes with univariate statistics; (2) estimating the pre- and post-CCT network structures; (3) analyzing the connections of a node with all other nodes in the network (i.e., nodes centrality); (4) calculating the

Table 1
Description of the CCT modules (adapted from Brito-Pons et al. 2019)

CCT protocol
Week 1—Cultivating stable and focused attention through breath-focused meditation and informal practices
Week 2—Cultivating compassion for a loved one by learning how to identify the physical and physiological feelings of warmth, tenderness, concern, and compassion
Week 3—Cultivating compassion for oneself by developing self-acceptance, non-judgment, and caring for oneself
Week 4—Cultivating loving-kindness for oneself by developing appreciation, joy, and gratitude for oneself
Week 5—Cultivating common humanity by recognizing our shared common humanity and the deep interconnectedness of human beings
Week 6—Cultivating compassion for others by moving progressively the focus from a loved one to a neutral person, a difficult person, and finally to all beings
Week 7—Cultivating active compassion by evoking the altruistic wish to alleviate others' suffering through the practice of *tonglen* ("giving and taking"), a visualization where the practitioner imagines taking away the suffering of others and giving them what is beneficial in oneself
Week 8—Integrating compassion by practicing an integrated compassion meditation combining all the previous components

amount of variance of each node statistically explained by all other nodes in the network (i.e., predictability); (5) exploring whether the network is reorganized in different clusters of nodes after the CCT (i.e., communities); (6) estimating the nodes that act as connectors between the five domains of variables included in the study (i.e., bridge centrality); and

Table 2

Summary of measures

Mindfulness

- *Five-Facet Mindfulness Questionnaire-Short Form* (FFMQ, 20 items [$\alpha = 0.91$]; Baer et al. 2006).
  It includes five mindfulness skills: describing (FFMQ-D), acting with awareness (FFMQ-A), observing (FFMQ-O), non-judging of inner experience (FFMQ-J), and non-reactivity to inner experience (FFMQ-R).
- *Non-Attachment Scale* (NAS, 30 items [$\alpha = 0.95$]; Sahdra et al. 2010). It assesses the absence of excessive fixation of thoughts and mental images, as well as the absence of the internal pressure of hold, change, or avoid any experiences.
- *Experiences Questionnaire* (EQ, 11 items [$\alpha = 0.90$]; Fresco et al. 2007).
  It measures the ability to observe, without attaching oneself, our feelings, and thoughts.
- *Multidimensional Assessment of Interoceptive Awareness* (MAIA, 32 items [$\alpha = 0.96$]; Mehling et al. 2012).
  A measure of interoceptive body awareness

Compassion

- *Self-Compassion Scale-Short Form* (SCS-SF, 12 items [$\alpha = 0.91$]; Raes et al. 2011).
  It measures compassion to oneself through three components: mindfulness (SCS-M), self-kindness (SCS-A), and common humanity (SCS-H).
- *Compassion Scale* (CSP, 24 items [$\alpha = 0.90$]; Pommier et al. 2019). It assesses compassion to others.
- *Interpersonal Reactivity Index* (IRI, 14 items [$\alpha = 0.74$]; Davis 1980). It measures empathy towards others.
  In this study, only the Empathic Concern subscale (IRI-E) was included.

Psychological well-being

- *Satisfaction With Life Scale* (SWLS, 5 items [$\alpha = 0.90$]; Diener et al. 1985). It measures global life satisfaction.
- *Life Orientation Test–Revised* (LOT-R, 10 items [$\alpha = 0.68$]; Scheier et al. 1994). It measures dispositional optimism.
- *Pemberton Happiness Index* (PHI, 11 items [$\alpha = 0.93$]; Hervás and Vázquez 2013). It measures hedonic and Eudaimonic components of psychological well-being.

Psychological distress

- *Depression Anxiety Stress Scales* (DASS-21, 21 items [$\alpha = 0.95$]; Lovibond and Lovibond 1995).
  It assesses symptoms of depression (DASS-D), anxiety (DASS-A), and stress (DASS-S).

Emotional and cognitive control

- *White Bear Suppression Inventory* (WBSI, 10 items [$\alpha = 0.92$]; Wegner and Zanakos 1994).
  It measures the tendency to suppress unwanted intrusive thinking.
- *Ruminative Response Style* (RRS, 22 items [$\alpha = 0.93$]; Nolen-Hoeksema and Morrow 1991).
  It measures rumination through two factors: cognitive reflection (RRS-R) and brooding (RRS-B).
- *Emotion Regulation Questionnaire* (ERQ, 10 items [$\alpha = 0.69$]; Gross and John 2003).
  It measures two emotional regulation strategies: reappraisal (ERQ-R) and suppression (ERQ-S).
- *Attentional Control Scale* (ACS, 20 items [$\alpha = 0.71$]; Derryberry and Reed 2002).
  It assesses perceived ability in executive control over attention.

Note: Cronbach's alpha found in the current study

(7) analyzing the overall robustness of the results (i.e., accuracy and stability). The data are available at https://github.com/nirakara-lab/Compassion_Meditation_Training (doi: 10.5281/zenodo.3700657).

Results

Pre-/Post-Psychological Changes (Univariate Statistics)

Consistent with previous studies, *t* tests for repeated measures revealed significant pre-/post-significant increases on measures of mindfulness, compassion, well-being, and adaptive cognitive and emotional control that accompanied a significant decrease in psychological distress and maladaptive cognitive-emotional measures (Table 3).

In contrast, network analysis provides complementary information about the connections between these psychological constructs that cannot be achieved by standard univariate statistics. In network analysis, the focus is shifted from the changes in individual variables to the relation between them, thereby enabling visualization of structural psychological changes after intervention programs.

Table 3 Paired *t* test comparisons of pre-/post-measures in the constructs assessed in the CCT

Node/construct	Pre-CCT		Post-CCT		$t_{(95)}$	*d*
	Mean	SD	Mean	SD		
Mindfulness						
FFMQ-observing	3.70	0.74	4.06	0.73	− 6.43*	− 0.65
FFMQ-describing	3.63	0.74	3.83	0.65	− 3.07*	− 0.31
FFMQ-acting awareness	2.95	0.66	3.39	0.64	− 8.09*	− 0.83
FFMQ-non-judgment	3.64	0.87	4.15	0.64	− 7.24*	− 0.74
FFMQ-non-reactivity	3.20	0.57	3.59	0.50	− 6.75*	− 0.69
NAS	4.42	0.76	4.77	0.65	− 6.41*	− 0.65
EQ	3.33	0.56	3.82	0.50	− 9.50*	− 0.97
MAIA	3.08	0.80	3.50	0.69	− 8.08*	− 0.82
Compassion						
SCS-self-kindness	6.08	1.84	7.72	1.34	− 10.61*	− 01.08
SCS-common humanity	6.15	1.65	7.71	1.43	− 9.93*	− 1.01
SCS-mindfulness	6.19	1.75	7.67	1.41	− 10.00*	− 1.02
CSP	4.29	0.46	4.45	0.44	− 5.06*	− 0.51
IRI-empathic concern	28.49	4.02	29.14	4.17	− 1.93	− 0.20
Psychological well-being						
SWLS	23.28	6.05	24.91	5.33	− 3.49*	− 0.36
LOT	22.75	3.66	23.84	3.54	− 3.86*	− 0.39
PHI	79.63	17.25	87.41	14.97	− 5.90*	− 0.60
Psychological distress						
DASS-depression	0.55	0.64	0.28	0.36	4.75*	0.48
DASS-stress	1.04	0.60	0.71	0.38	5.28*	0.54
DASS-anxiety	0.44	0.51	0.30	0.29	3.01*	0.31
Emotional and cognitive control						
WBSI	30.66	8.76	27.82	7.98	4.07*	0.42
RRS-brooding	9.18	2.82	8.14	2.13	4.27*	0.44
RRS-reflection	10.94	2.79	9.99	2.63	3.82*	0.39
ERQ-reappraisal	26.56	6.93	28.61	6.15	− 3.51*	− 0.36
ERQ-suppression	11.20	4.59	9.48	3.80	4.92*	0.50
ACS	2.83	0.32	2.97	0.33	− 4.49*	− 0.46

*$p < .01$

SD, standard deviation; *d*, Cohen's *d* effect size

Description of the variables and their acronyms is shown in Table 2

Pre- and Post-CCT Network Estimation

Figure 2 shows the regularized partial correlation networks before and after the CCT (see also the principal component analysis plot in Supplementary Figure 1). To complement interpretations based on visual inspection of the networks (Jones et al. 2018), we conducted correlational analyses to identify some relevant features of the networks.

First, before the CCT, self-compassion measures (i.e., SCS) were negatively related to dysfunctional emotional and cognitive control measures (i.e., brooding [RRS-B], emotional suppression [ERQ-S], and thought suppression [WBSI]). Yet, after the program, SCS measures increased their strength of association with a number of adaptative emotional and cognitive control measures (i.e., emotional reappraisal [ERQ-R] and cognitive reflection [RRS-R]). Furthermore, these SCS measures became more strongly associated with the array of mindfulness measures (increasing the connections with decentering [EQ], non-attachment [NAS], acting with awareness [FFMQ-A], and non-judging [FFMQ-J]). Interestingly, self-compassion was strongly associated with the non-judgmental component of mindfulness (FFMQ-J), whereas it was largely disconnected from compassion to others and empathy measures (i.e., CSP and IRI-E), both before and after the CCT. In fact, compassion toward others (CSP) and empathic concern (IRI-E) formed a strong dyad both before and after the CCT.

Second, before the CCT, regarding emotion regulation measures, emotion reappraisal (ERQ-R), an adaptive emotion regulation strategy, was related to mindfulness (MAIA, FFMQ-R, and FFMQ-D) and well-being measures (SWLS and PHI). However, after completing the program, reappraisal was related to self-compassion measures (SCS variables). Regarding emotional suppression (ERQ-S), a non-adaptive emotional regulation strategy, before the program, it showed negative connections with describing and observing facets of mindfulness (FFMQ-D and FFMQ-O) and with common humanity (SCS-H). However, after the CCT, emotional suppression (ERQ-S) was strongly and negatively correlated with compassion toward others (CSP).

Third, regarding rumination measures, brooding (RRS-B) had the strongest negative edges (associations) in the network before the CCT: negative relations with non-attachment (NAS), well-being (SWLS and LOT), and self-compassion (SCS-H and SCS-M). Yet, most of these relations weakened after the program. The reflection component of rumination (RRS-R) was positively related to dysfunctional variables (e.g., depression, anxiety, or brooding) before, but not after, the program.

Pre- and Post-CCT Network Inference

Overall, the constructs with the highest strength and expected influence (Robinaugh et al. 2016), both before and after the CCT, were several mindfulness measures (non-attachment [NAS], decentering [EQ], and interoceptive body awareness [MAIA]), compassion measures (self-compassion [SCS] and compassion toward others [CSP]), general well-being (PHI), and psychological distress (DASS) (Supplementary Figure 2). The Network Comparison Test (NCT; van Borkulo et al. 2017) examined whether the overall network connectivity significantly differed between pre- and post-CCT networks. The NCT showed no significant differences between pre- and post-

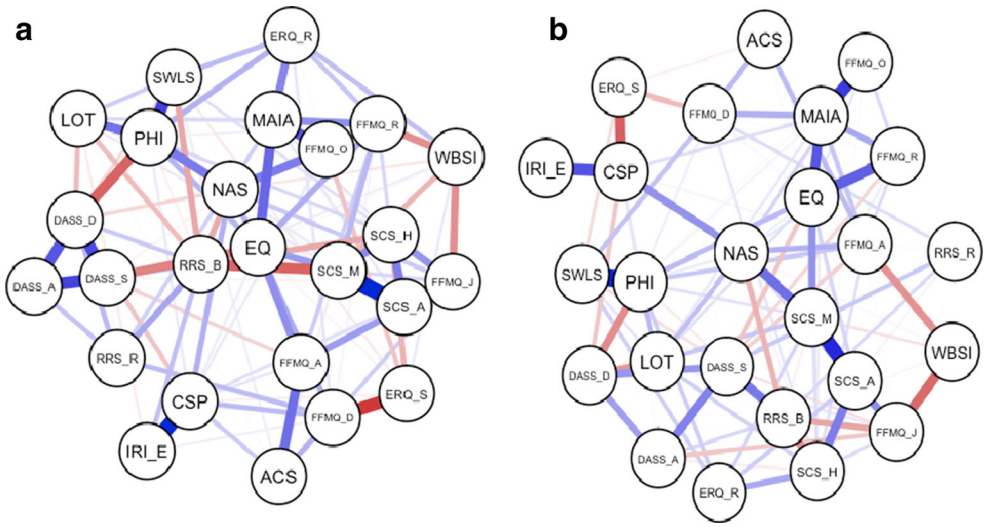

Fig. 2 Regularized partial correlation networks before (panel **a**) and after (panel **b**) the CCT. The networks are graphed by nodes (i.e., circles representing the psychological constructs described in Table 2) and edges (i.e., lines representing correlations between the different nodes). Blue edges represent positive correlations between nodes whereas red edges represent negative ones. The nodes' spatial position within the networks is chosen by the Fruchterman-Reingold algorithm, placing close together those nodes with stronger and/or more connections while it places nodes with low centrality in the periphery. See the list of node names in Table 2

CCT networks in the overall network structure (M = 0.25; p = .26), the global network strength (S = 1.20; p = .15), and the global network expected influence (S = 0.86; p = .33). However, there were pre- vs post-CCT statistically significant differences in the strength and expected influence of some specific edges and nodes. There was a significant strength reduction after the CCT in depression (DASS-D), the brooding component of rumination (RRS-B), and non-reactivity to inner experience (FFMQ-R), whereas there was a significant EI reduction of anxiety (DASS-A) and non-judgment (FFMQ-J). Reduction in global strength implies that activation of certain nodes (e.g., rumination) is less likely to co-occur with other nodes (e.g., depression) following the intervention. Furthermore, there was a significant EI increase of mindfulness self-compassion (SCS-M), whereas common humanity (SCS-H) was the node with the highest degree centrality increase after the CCT (i.e., SCS-H became highly interconnected to other nodes after the program). Finally, the nodes with the highest clustering increase after the CCT were emotional suppression (ERQ-S), thought suppression (WBSI), and anxiety (DASS-A), indicating that the neighbors of these nodes were more interconnected them after CCT.

Pre- and Post-CCT Node Predictability

Figure 3 shows the pre-/post-CCT predictability values for each node (i.e., how much variance of a node can be explained by other nodes in the network). The nodes with the highest predictability values before CCT were related to self-compassion (SCS-M = 0.84, SCS-A = 0.74, and SCS-H = 0.71), mindfulness (EQ = 0.79, NAS = 0.77, and MAIA = 0.70), general well-being (PHI = 0.83), and psychopathology-related constructs, such as depression (DASS-D = 0.83), anxiety (DASS-S = 0.74), and brooding (RRS-B = 0.81). Interestingly, while self-compassion, mindfulness, and well-being predictability values remained stable after the program (see Supplementary Figure 3), the predictability of psychopathology-related constructs declined markedly after the CCT: depression (DASS-D; R^2_{pre} = 0.83, R^2_{post} = 0.56), anxiety (DASS-A; R^2_{pre} = 0.66, R^2_{post} = 0.41), stress (DASS-S; R^2_{pre} = 0.74, R^2_{post} = 0.61), brooding (RRS-B; R^2_{pre} = 0.81, R^2_{post} = 0.64), and emotional suppression (ERQ-S; R^2_{pre} = 0.44, R^2_{post} = 0.28). The pre- and post-CCT average predictability values were quite similar (0.61 and 0.57, respectively), and no significant differences were found between pre- and post-CCT predictability ($t_{(24)}$ = 2.29; p > .01). In other words, there was an overall average of 59% of the variance of a node predicted by all its neighbors. According to Haslbeck and Fried (2017), this signifies a high degree of predictability both before and after CCT.

Pre- and Post-CCT Network Node Communities

The spinglass algorithm detected five communities (i.e., cluster of nodes), both before and after CCT. Minor changes were observed in the communities' reorganization after the program (see Fig. 4). Five communities remained largely unchanged after CCT: (1) the "psychopathological community" (cluster C, depicted in green) comprised the same nodes after the program (i.e., psychological distress and rumination), excepting emotional suppression (ERQ-S) that appeared with the mindfulness variables in cluster B; (2) the "self-compassion community" (cluster B depicted in blue) became the largest cluster after the CCT, now including nodes related to emotional regulation (ERQ-S and ERQ-R), non-attachment (NAS), and optimism (LOT); (3) the "mindfulness community" (cluster D, depicted in yellow) retained mostly the same nodes. However, several mindfulness nodes now appeared in different communities (clusters A, B, and D) after CCT; (4) cluster A included well-being measures (general well-being [PHI] and life satisfaction [SWLS]) joined by attentional control (ACS), acting with awareness (FFMQ-A), and describing (FFMQ-D). Cluster E included only compassion toward others (CSP) and empathic concern (IRI-E).

Pre- and Post-CCT Bridge Centrality

Estimates of one-step bridge expected influence are plotted in Supplementary Figure 4. Prior to the intervention, the three nodes scoring highest on this bridge centrality metric belonged to the emotional-cognitive control community (cognitive reflection [RRS-R = 0.38], emotional reappraisal [ERQ-R = 0.53], and attentional control [ACS = 0.41]), one to the mindfulness community (body awareness [MAIA = 0.39]), and one to the compassion community (compassion to others [CSP = 0.36]). Two self-compassion measures (self-kindness [SCS-A = 0.36], mindfulness self-compassion [SCS-M = 0.65]), two nodes from the mindfulness community (non-attachment [NAS = 0.45] and decentering [EQ = 0.35]), and emotional reappraisal (ERQ-R = 0.48) remained as high bridge nodes after the program. Interestingly, no psychological distress or psychopathological emotional-cognitive control measure appeared as a bridge node in the CCT networks.

Finally, we assessed the accuracy and stability of the networks (see further details in Supplementary Materials). Although estimated pre- and post-CCT networks appear reliable (see Supplementary Figure 5), the inferences drawn from centrality analyses should be interpreted cautiously due to the modest sample size and the low stability of the networks (see Supplementary Figure 6).

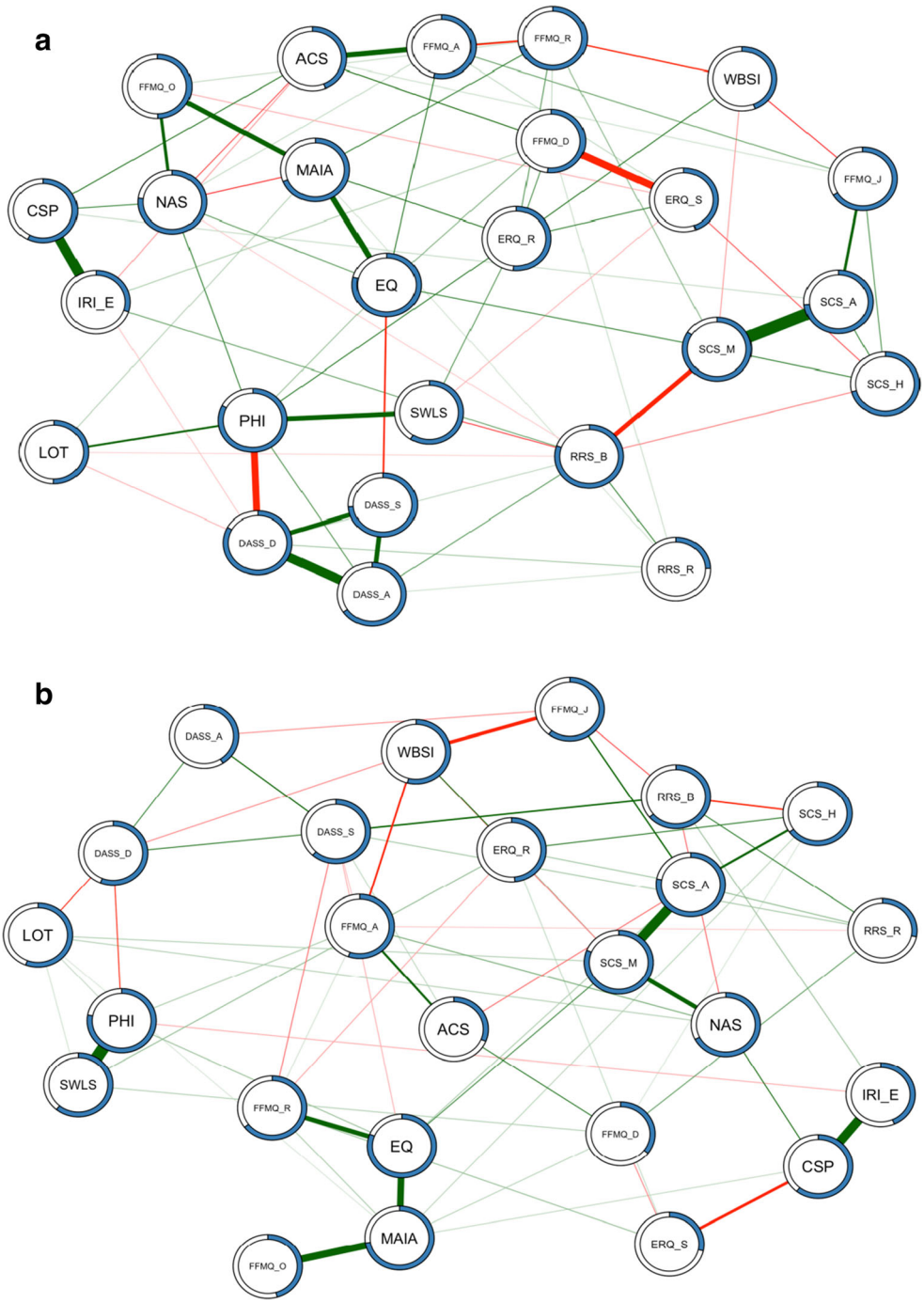

Fig. 3 Node predictability before (panel **a**) and after CCT (panel **b**). The blue ring around each node represents the percentage of variance predicted by all its neighbors. Positive relations between nodes are represented with green edges and negative relations with red ones. See the list of node names in Table 2

Discussion

The general aim of the study was to examine, by using network analysis, whether a standardized compassion program could change the structure of relations among different psychological constructs theoretically relevant for meditation and compassion practices. CCT yielded significant changes in almost all measures in the expected directions, replicating previous studies (Brito-Pons et al. 2018; Goldin and Jazaieri 2017; Jazaieri et al. 2014). Furthermore, effect sizes indicated that the magnitude of these changes ranged from medium to large.

Using network analytic methods, we tested whether CCT would promote a favorable topological reorganization of the psychological constructs by which compassion variables become more connected with other variables measuring wellness and adaptive cognitive and emotional control. We found several notable changes in network topology following CCT. Changes in compassion-related measures were especially notable. Self-compassion measures were negatively related to

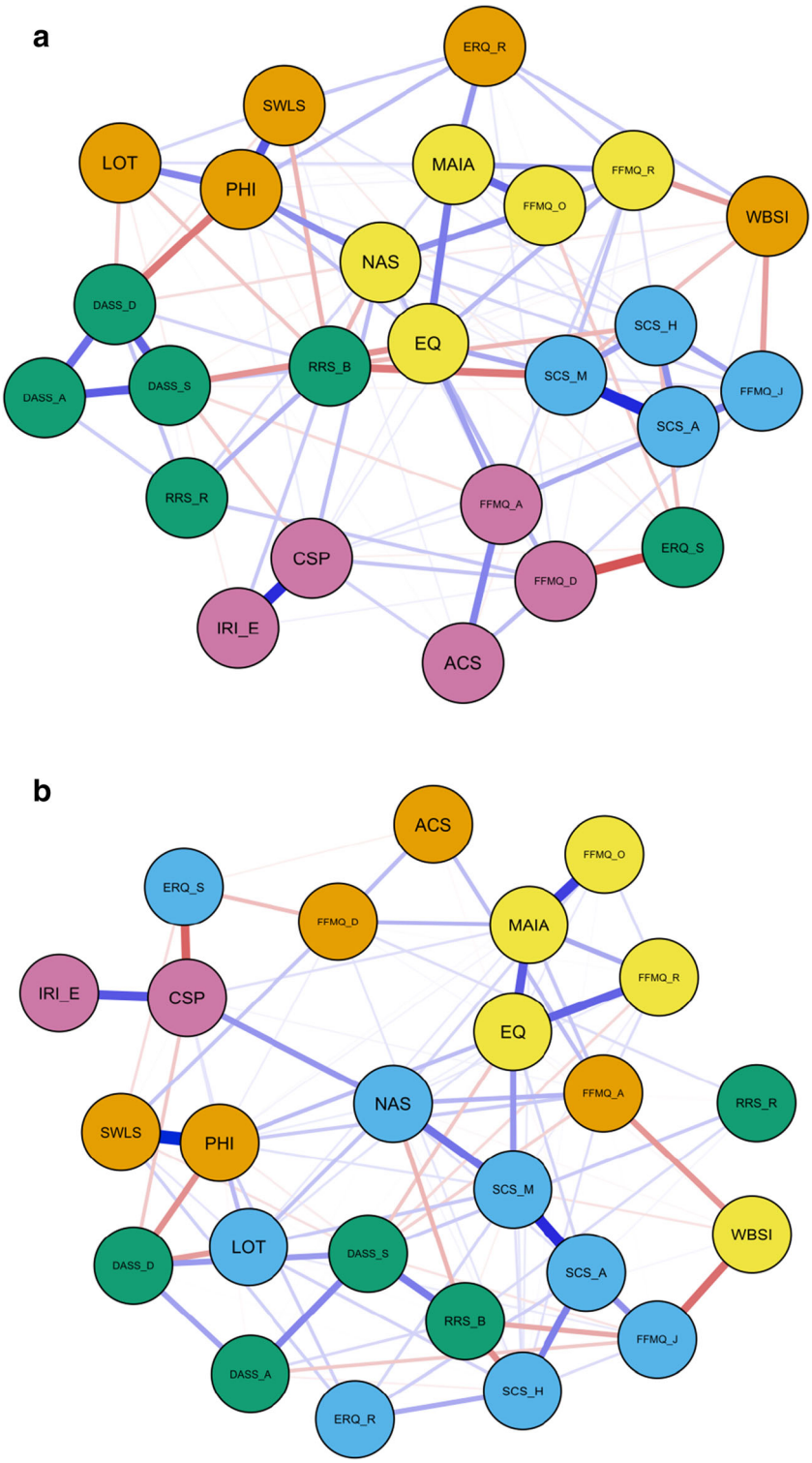

Fig. 4 Community detection analysis performed on pre- (panel **a**) and post- (panel **b**) CCT networks. The identified communities depict the variables that are more strongly inter-correlated. See the list of node names in Table 2

dysfunctional emotional and cognitive control measures (e.g., rumination and emotional suppression) before CCT, but positively associated with adaptive variables (i.e., emotional reappraisal and cognitive reflection) after the program. Also, self-compassion was more strongly associated with mindfulness variables after CCT. These findings suggest that self-compassion plays a key role in adaptive emotional self-regulation (Neff 2011). Emotion regulation often mediates the relation between self-compassion and positive mental health outcomes (Finlay-Jones 2017; Inwood and Ferrari 2018), and CCT enhances emotion regulation processes (Jazaieri et al. 2014, 2018). Our finding that reappraisal

becomes strongly associated with self-compassion after CCT suggests that increasing one's ability to be compassionate with oneself may enable people to reappraise situations in a less destructive way (Gilbert 2019). On the other hand, non-adaptive suppression of emotions (Gross 2001) became negatively associated with compassion for others after CCT. Hence, becoming aware of the suffering of others is associated with a diminished likelihood of suppressing one's own emotions. Brooding, a passive, judgmental evaluation of one's mood (Nolen-Hoeksema and Morrow 1991), diminished after CCT. Its connections with other nodes diminished as well (i.e., non-attachment, well-being, and self-compassion). This finding makes sense as brooding seems incompatible with the motivation to alleviate the suffering characteristic of compassion (Strauss et al. 2016).

We found nodes signifying compassion, mindfulness, and well-being were especially central both before and after CCT. Expected influence and strength centrality indices were highest for compassion (self-compassion and compassion toward others) and mindfulness variables (non-attachment, decentering, and interoceptive body awareness) both before and after CCT. Furthermore, self-compassion, non-attachment, and decentering were the highest bridges nodes (i.e., the nodes most likely to activate nearby communities of nodes). These bridge nodes would act as "modulators" of the different sub-networks (i.e., communities). For instance, in the case of psychological distress (i.e., DASS nodes) and rumination (i.e., RRS-Brooding), non-attachment and self-compassion served this purpose, decoupling psychopathological variables from the rest of the network. Something similar happens in brain dynamics, where some networks serve as inhibitors of others (Menon 2011). Therefore, bridge centrality is especially meaningful to interpret the CCT-induced changes because the function of bridge nodes is to distribute the information through the network, acting as mechanisms to couple sub-networks of adaptive variables (e.g., self-compassion, mindfulness, well-being), while decoupling sub-networks of non-adaptive variables (e.g., psychological distress, rumination, emotional suppression). Future studies should test these adaptive and non-adaptive sub-networks separately in order to (1) analyze the structure of each sub-network, under the hypothesis that psychological interventions should couple adaptive sub-networks while decoupling non-adaptive ones; and (2) calculate the predictability in each sub-network instead of global predictability. If there is an increase of predictability after the program in the adaptive sub-networks and a decrease in the non-adaptive ones, then the intervention has enhanced the consolidation of overall positive states which, in turn, would act as "protective dynamic sub-networks" inhibiting the influence of other non-adaptive sub-networks once they are activated. A similar protective function has been found in animal ecosystems and even in bacterial networks (Castellanos et al. 2020).

Our results are compatible with previous findings showing that compassion programs target both compassion and mindfulness skills (Brito-Pons et al. 2018; Jazaieri et al. 2014; Kirby et al. 2017) by using mainly explicit or implicit strategies, respectively (Brito-Pons et al. 2018). Furthermore, most compassion meditation exercises include mindfulness skills in the learning process, which is the focus of the first module of CCT (Goldin and Jazaieri 2017). Within mindfulness skills, non-attachment had a central role in CCT networks. Non-attachment is defined as the absence of fixation on thoughts, emotions, or sensory objects, as well as an absence of internal pressure to change, approach, or avoid these experiences (Sahdra et al. 2010). Our results are in line with those showing that non-attachment is one of the main mechanisms of action in meditation-based programs (Hölzel et al. 2011; Tanay et al. 2012), expanding this finding to compassion programs. Thus, non-attachment would promote a change in the perspective on the self that is crucial for understanding the effects of meditation (Gunaratana 2009).

On the other hand, although there were no significant changes in the global network structure, there was a significant reorganization of the edges and nodes contributing to network strength and expected influence, which was consistent with our third hypothesis. The nodes with the highest expected influence and strength reduction after CCT were depression, anxiety, brooding, non-judgment, and non-reactivity to inner experience, whereas self-compassion measures exhibited the greatest increase in centrality after CCT. Although these changes may partly be attributable to regression toward the mean, they are also in accord with previous findings (Kirby et al. 2017; Neff 2003b). The results indicate not only reductions in depression, anxiety, and rumination average scores after CCT but also that their centrality diminished as well. Whereas mindfulness programs are primarily a cognitive practice in which "bare attention" (i.e., the ability to notice sensations, thoughts, and emotions) is cultivated (Wallace and Shapiro 2006), compassion programs are rather emotion-focused as participants are trained to be aware of ones and others' suffering (Jinpa 2010).

A previous research has found that mindfulness and well-being became the most central nodes after participants had undergone a Mindfulness-Based Stress Reduction (MBSR) program, whereas attentional control, depression, thought suppression, and several compassion measures were the nodes with the highest centrality changes after the program (Roca et al. 2019). Taken together, these results and the present ones suggest that there are common and specific mechanisms of change in MBSR and CCT. Whereas in both programs, mindfulness variables are among the most central nodes in their respective networks, well-being variables are more central in the MBSR network and compassion variables are more central in the CCT network. Also, whereas some of the nodes with the highest centrality change after the program seem to be similar

in both programs (i.e., depression and some non-adaptive cognitive control measure such as brooding or thought suppression), other changes seem specific to each program (e.g., the centrality changes in attentional control only appear after the MBSR program).

Although compassion toward others was largely disconnected from self-compassion, it was a highly central node, strongly connected with empathic concern, non-attachment, and negatively correlated with emotional suppression. In this study, we used the Compassion Scale (Pommier et al. 2019) as a measure of compassion for others. The operationalization of this scale was similar to Neff's (2003a) self-compassion model, measuring compassion for other's suffering in terms of attention (i.e., mindfulness), cognitive understanding (i.e., common humanity), and emotional responding (i.e., kindness). Surprisingly, although both scales come from the same theoretical model, the correlation between self-compassion and compassion toward others is usually small to medium (Pommier et al. 2019). Given that the general factor in the Compassion Scale accounts for a substantial amount of variance in the response (Pommier et al. 2019), we decided to use the total score in the networks. However, it is likely that the separate components of the scale may have different connections with other variables within the network. Furthermore, despite the importance of being aware of others' suffering, futures studies should include measures of the "action" component of compassion (i.e., behaviors intended to alleviate the suffering of others), such as the Compassionate Engagement and Action Scales (Gilbert et al. 2017) or observations of actual compassionate behaviors. Future studies should also examine the discrepancies between self- and other-compassion as a potential mechanism of the CCT program (e.g., do participants with greater self-/other-compassion discrepancies behave differently than those with low compassion discrepancies?).

Consistent with our fourth hypothesis, compassion, mindfulness, and well-being were the most predictable nodes (i.e., variance explained by other nodes in the network), both before and after CCT. Also, psychopathology-related constructs (i.e., depression, anxiety, stress, brooding, and emotional suppression) exhibited reductions in predictability after the program, suggesting that psychological distress and psychopathology-related measures became less connected to other variables following CCT. Interestingly, these psychopathological nodes not only decreased their predictability after the program but also became less interconnected to each other. In other words, these symptoms tend to "decouple" when individuals improve their mental health. For instance, when a person is stressed out, an increase in stress and anxiety would lead to an increase in depression and rumination, whereas when the person learns how to regulate his or her emotions and thoughts after practicing compassion, an increase in stress and anxiety would not lead to an increase in depression and rumination. The opposite is also true for the well-being nodes: before the CCT program, well-being variables were decoupled in the network (i.e., less predictable), whereas after the program, well-being variables became more coupled by increasing their correlations with the variables trained in the program (i.e., compassion and mindfulness skills).

Inconsistent with our fifth hypothesis, community detection analyses revealed that the five clusters of nodes detected before CCT (i.e., psychopathology, self-compassion, mindfulness, well-being, and compassion) remained largely intact following the program. This result contrasts with our previous study that showed a community reorganization among nodes following MBSR in accordance with theoretical expectation (Roca et al. 2019). Interestingly, the pre-CCT communities in the present study were very similar to those of the post-MBSR communities in Roca et al.'s (2019) study a finding potentially attributable to differences in the percentage of participants with previous meditation experience in our CCT participants (85.4%) than in Roca's MBSR group (56.0%). The difference is unsurprising because mindfulness skills are typically taught before compassion skills in meditation programs (Dahl and Davidson 2019) and, for many participants, compassion training commences only after one has undergone mindfulness training.

Network analysis is a relatively novel way to elucidate mechanisms of change in compassion programs, extending the potential use of the "psychonectome" perspective (Roca et al. 2019) to other meditation practices as well as other interventions aimed at promoting well-being (Blanco et al. 2020). Although latent variable and network models are ontologically distinct (McNally 2020), they are statistically fungible (van Bork et al. in press). Accordingly, we drew on both approaches in the present study. Furthermore, our study combines state-of-the-art network analysis procedures (including a sequential network analysis procedure based on six steps), together with novel centrality metrics (i.e., expected influence, bridge centrality), plus a robust set of measures tapping key components of compassion.

Limitations and Future Research Directions

Our study has limitations. The number of participants per node was modest. Moreover, although our networks were reasonably reliable, the stability of the centrality estimates was low. Also, most participants had previous meditation experience from different traditions. Although this might have influenced our results, few individuals enrolling in compassion programs lack prior meditation experience. Another limitation of the study was that only post-intervention changes were analyzed. Although still infrequent in the meditation literature, future studies should include longitudinal designs to facilitate inferences on directionality and causality of the networks

(Borsboom and Cramer 2013; Gao et al. 2017). Given that multiple constructs were measured with common methods (i.e., multiple-item scales presented within the same survey), there might be spurious correlations among the constructs, also known as common method biases (Podsakoff et al. 2003). Although we used partial correlations to compute our networks (i.e., a statistical remedy to minimize these problems), future studies might overcome these limitations by obtaining measures from different sources, including behavioral or psychophysiological indicators (e.g., Kim et al. 2020b). A more comprehensive mechanistic approach of MBIs could be achieved in integrating these types of variables in network analysis as some authors have begun to do (e.g., Heeren and McNally 2016). Future analyses should include attentional performance as one of the nodes of the networks (Roca and Vazquez 2020). Finally, it is also important to interpret the present results with caution as network analysis methods are still under development in psychology. The robustness of these results would be supported if future research replicates them with other meditation types (e.g., deconstructive practices), meditation experience (e.g., novices vs experts), clinical populations (e.g., mood disorders), and practice settings (e.g., meditation retreats).

In sum, our study contributes to research on compassion. Network analysis provides a novel perspective on changes induced by compassion training, such as CCT that implicate specific mechanisms of change. Our study shows that, after CCT, the map of variables is reorganized such that compassion becomes more connected with measures related to well-being and adaptive functioning. Also, compassion treatment seems to reduce the role that negative repetitive thoughts (i.e., brooding) may have in the entire network. This finding suggests that compassion may figure as an ingredient of therapies aimed at reducing emotional disorders by targeting rumination (e.g., Watkins 2015). Finally, high gains of compassion in network centrality seem to validate that CCT is truly operating by directly increasing the purposed mechanism of compassion whereas, by comparison, MBSR trainings seem to increase the centrality of attentional variables (Roca et al. 2019). In sum, network analysis illuminates the distinctive pathways through which different MBIs seem to operate. We hope that our study encourages researchers to undertake research including variables, other than those of self-report, to deepen our understating of why and how meditation interventions work.

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Author Contributions PR and CV developed the study conception and design. Testing and data collection were performed by PR and GD. Data analysis and interpretation were performed by GD and PR. The first draft of the manuscript was written by PR, under the close supervision of CV and RM. PR, CV, and RM drafted the manuscript. All the authors approved the final version of the manuscript for submission.

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Compliance with Ethical Standards

Participants provided informed consent prior to their inclusion in the study. Furthermore, the study was approved by the Complutense University ethics committee prior to participant recruitment and was registered at ClinicalTrial.org (NCT03920241).

Conflict of Interest The authors declare that they have no conflict of interest.

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