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The network architecture of individual differences: Personality, reward-sensitivity, and values☆

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ABSTRACT

Individual differences in behavioral dispositions, values and motivation systems have been investigated in relative isolation from each other. We investigated the network structure of indicators derived from Reinforcement Sensitivity Theory, Five-Factor Model and Basic individual values in a large sample of young adults (N = 749). The network showed evidence of a small world structure indicating a small number of densely connected networks is sufficient to describe human personality. We identified a number of nodes (indicators) that were central within the network. An Exploratory Graph Analysis suggested ten distinct network clusters, which varied in terms of behavioral approach versus inhibition; exploration vs constraint and self/ego vs social orientation, demonstrating the complexity of individual differences from a motivational-situational perspective. A more complex dimensional exploration of personality networks allows for a more nuanced understanding of how personality systems can be motivated within specific environments and towards different internal or external targets.

1. Introduction

The structure of neurobiological foundations of human traits and values have fascinated researchers for decades. Eysenck's (1947, 1967) work was central for both mapping stable individual differences and linking them to neurobiological systems. Following in Eysenck's footsteps, we aim to link neurobiological models of personality (Corr & McNaughton, 2008), the Big Five (John & Soto, 2017) and human values (Schwartz et al., 2012) to identify the salient nodes and networks that may cut across these different instruments. Our focus on network architecture of individual differences will allow identification of behavioral indicators which enjoy greater centrality within a behavioral network and may be suitable targets for behavioral interventions and neurobiological explorations.

Inspired by Eysenck's earlier work on Neuroticism and Extraversion, Gray (1970, 1982) developed the Reinforcement sensitivity theory (RST) which differentiates between broad motivational approach and behavioral inhibition or defensive mechanisms from a neurobiological perspective (see Kennis, Rademaker & Geuze, 2013). Corr and McNaughton (2008) revised the theory by differentiating the behavioral approach system (BAS) from the behavioral inhibition system (BIS, related to anxiety) which regulates motivational conflicts and the fight-flight-freeze system (FFFS; related to fear; previously included in a larger behavioral inhibition system). The BAS consists of a number of subsystems that facilitate goal attainment along the temporo-spatial continuum. These subsystems range from goal identification defined by anticipation and interest (Reward Interest), to goal obtainment via fast action (Impulsivity) or planning and persistence (Goal Drive Persistence) all the way to emotional excitement and behavioral reinforcement when goals are completing or near completion (Reward Reactivity). The empirical distinction of these BAS subsystems remains a major theoretical and empirical challenge (see Corr, 2016; Corr & Krupic, 2017, Krupić, Corr, Ručević, Križanić & Gračanin, 2016), with only the RST-PQ (Corr & Cooper, 2016) so far empirically differentiating evolutionary salient motives in approach motivation (Krupić, Gračanin & Corr, 2016).

Within personality psychology, the Five Factor model (DeYoung, 2015; Digman, 1990; Goldberg, 1990) specifies five phenotypic traits: Extraversion, Agreeableness, Openness, Conscientiousness and Neuroticism/Emotional Stability. Within these five factors a number of sub-traits of more specific behavioral content can be distinguished. For example, the BFI-2 differentiates Extraversion into sociability, assertiveness and energy components (John & Soto, 2017). The five traits partially map onto the neurobiologically derived RST

Data and supplementary information available on OSF: https://osf.io/wf26d/

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systems: Neuroticism is strongly correlated with BIS in particular; Extraversion is conceptually related to all BAS subsystems, Conscientiousness is related to BAS Goal-Drive Persistence, but also weakly negatively to BIS (it requires both goal persistence and monitoring goal conflicts), Openness is correlated with BAS Reward Interest (since it is anticipatory and involves reward simulation) and Agreeableness typically shows weak but positive correlations with all BAS components, except BAS Impulsivity (Antoniazzi & Klein, 2019; Corr & Cooper, 2016; Pugnaghi, Cooper, Ettinger & Corr, 2018).

Within social psychology, a different motivational system based on basic human values was proposed by Schwartz (1992; Schwartz et al., 2012) who distinguished between two major motivational axes that give rise to a circular structure based on the underlying motivational compatibilities and conflicts. The first axis is defined by Openness to change values (stimulation, self-direction) emphasizing one's independent thoughts, actions, and interests; these are opposed by Conservatism values (security, conformity, tradition) emphasizing restricting oneself, the preservation of traditional practices, and upholding the status quo. The second axis is defined by Self-Enhancement values (power, achievement) emphasizing pursuing personal success (even at the expense of others) and the motivation to dominate over others; these are opposed by Self-Transcendence values (universalism, benevolence) emphasizing the promotion of the well-being of others and nature. This circular structure has been supported using self- and other reports, reaction time, and neuroscience studies (see Fischer, 2017; Maio, 2016). FFM traits and basic human values are conceptually and empirically related, with Openness traits correlating with openness values, Agreeableness with self-transcendence values, Extraversion with both openness and self-transcendence values, Conscientiousness with conservative and self-enhancement values and only Neuroticism showing weak correlations with values (Fischer & Boer, 2015).

The overall pattern in these studies suggest that there are potentially common underlying biological mechanisms that give rise to these empirically observed covariations (Fischer, 2017). Using the RST as the lowest level neurobiologically oriented reference point, BIS as the central system for monitoring goal conflicts and constraining of impulses may provide the motivational foundation for conservative values (e.g., Eaves & Eysenck, 1974) and Neuroticism, as well as potentially Conscientiousness; BAS as the major system for exploring and pursuing rewarding goals might give rise to openness to change values, Extraversion, and Openness (Corr & Krupic, 2017; Corr & McNaughton, 2008; Fischer, 2017). The role of the FFFS is less clear, it seems primarily related to Neuroticism (Antoniazzi & Klein, 2019; Corr & Cooper, 2016; Pugnaghi et al., 2018).

1.1. Definition of network parameters

We explore the relationship between these instruments using a network approach (Costantini et al., 2015), which describes a network based on indicators (nodes) and their relationships with each other (edges). The analysis of the network architecture can provide novel insights into the structure of personality because it does not assume that there are latent variables which underlie correlations between locally independent indicators. To paraphrase Cramer et al. (2012), people who like parties are likely to meet more people which in turn become friends and invite them to other parties. Hence, the local associations between measured indicators can provide insights into a behavioral ecosystem that gives rise to behavioral consistencies.

A number of network parameters can provide useful insights for understanding these dynamics. First, an analysis of the whole network can indicate whether there is a limited number of densely connected behavioral clusters (a so-called small-world network; Watts & Strogatz, 1998). A network with small-world properties indicates that the relationship between item clusters is governed by a limited number of key nodes (indicators). Within the network, it is possible to identify core nodes (indicators) that characterize the network. We will focus on strength, betweenness, and closeness of the individual nodes (Costantini et al., 2015). Strength is a generalization of degree centrality identified as the number of connections to each node (item) weighted for the combined strength of edges connected to the node (item). Nodes (items) high in strength can be expected to have a direct impact (or be impacted by) many different nodes (items) without the mediating effect of other nodes (items) (Barrat, Barthélemy, Pastor-Satorras & Vespignani, 2004; Newman, 2004). Betweenness captures the path length between two other nodes passing through the item of interest. In other words, a high betweenness index indicates that a node is central for connecting two or more nodes (items), similar to a broker connecting other agents. Finally, closeness is similar to flow speed through the network (Borgatti, 2005; Freeman, 1978; Sabidussi, 1966), the extent to which a node acts like 'superconductor' quickly connecting other nodes either directly or indirectly mediated by other nodes. Hence, these various indicators can provide complementary information on the centrality of an item in terms of the number of connections, the quality and speed of those connections within a network. The computation of assortative coefficients also provides some information on the plausibility (internal consistency) of the individual instrument dimensions. Finally, we use Exploratory Graph Analysis (Golino & Eskamp, 2017) to identify central clusters (conceptually similar to latent variables) that may organize the larger network and we will map the resulting cluster to identify possible theoretical dimensions. RST proposes at least three behavioral dimensions, value researchers distinguish at least two major dimensions and personality researchers describe five traits. We test the contributions that a network approach can bring to the joint consideration of these instruments and theoretical perspectives.

2. Method

2.1. Participants

We sampled 749 young adults taking part in the research in exchange for research credit. Overall, 26.44% of our sample were male with a mean age of 19.87 (SD = 4.79). A total of 23 participants had missing data in their responses and were excluded. The full data set including those 23 cases is available on the OSF. Ethical approval was provided by the School of Psychology Human Ethics Committee under delegated authority of Victoria University of Wellington's Human Ethics Committee.

2.2. Measures

Information on reliability, descriptive statistics at the construct level, data and R code are available on the project site on OSF (https://osf.io/wf26d/). All analyses were conducted in R (R Core Team, 2019).

Personality. We used the BFI-2 to assess personality (Soto & John, 2017). This scale measures the five personality-dimension with three subscales each. The overall scale had 60 items and participants reported their agreement with each item on a 1 (Disagree strongly) to 5 (Agree strongly) Likert-scale. Example items were "I am someone who is outgoing, sociable" and "I am someone who is compassionate, has a soft heart".

Behavioral Approach vs Inhibition Motivation. We used the Reinforcement Sensitivity Theory of Personality Questionnaire (RST-PQ; Corr & Cooper, 2016). All 42 items were measured on a 7-point Likert scale ranging from 1 (Not at All) to 7 (Highly). Example items were "I am an avoidant sort of person" and "I often find myself not wanting to touch certain objects".

Values. We measured values with an adapted gender-neutral version of the PVQ-57RR (Schwartz et al., 2012). The overall scale had 57 items and participants reported their agreement with each item on a 1 (Not like me at all) to 6 (Very much like me) Likert-scale. Example

items were “It is important to him/her to form his/her views independently” and “It is important to him/her that his/her country is secure and stable.”

3. Results

3.1. Overall network structure

We estimated the network of relationships between the individual items using an adapted Least Absolute Shrinkage and Selection Operator (LASSO; Zou, 2006) approach in the *parcor* package (Kraemer, Schaefer & Boulesteix, 2009). LASSO is a regression approach that shrinks coefficients to obtain a network that faithfully represents the original network while also reducing near zero edges to exact zero (Constantini et al., 2015), with the adaptive LASSO introducing data-driven weights to counteract a potential bias towards large coefficients. Our network had 880 unique non-zero edges (representing 5.85% of total possible edges) indicating that the adaptive LASSO approach resulted in a sufficiently parsimonious network. The model contained substantially more positive (N = 722) compared to negative edges (N = 158). Additionally, the absolute average edge-weight of the positive nodes (M = 0.109, SD = 0.095) was significantly greater compared to negative edges (M = 0.056, SD = 0.029): t (804.34) = 12.507, p < .001, d = 0.606[.431, 0.780]. Overall, this indicates that our network is characterized by positive relationships between items, both in number and strength. We show the fitted model in Fig. 1 with colors indicating the individual constructs.

Next, we examined the small-world property of our network (Watts & Strogatz, 1998). The small-world property is defined as the tendency of a network to have both a high clustering coefficient and a short average path length; indicating highly dense and interconnected local clusters. Networks with a small-world index S above 3 have small-world properties, with values between 1 and 3 indicating borderline small-worldness (Humphries & Gurney, 2008). Our network had a value of 1.886, implying that our network nodes tend to form local clusters and a small number of key nodes govern the connection between those clusters (Costantini et al., 2015).

3.2. Network characteristics of the nodes

We examined the strength, betweenness, and closeness of the individual nodes. In our data these three indicators were positively related to each other: Strength-Closeness r = 0.65, Strength-Betweenness r = 0.71, Closeness-Betweenness r = 0.68. For interpretative purposes, we identified the top 5% nodes in our network based on betweenness centrality (Fig. 2), strength (Fig. 3), and closeness (Fig. 4, for the statistical parameters, see the OSF).

Two items consistently appeared in the top 5% of nodes across all three indicators (“Is reliable, can always be counted on” from the Responsibility facet of Conscientiousness; “Is dominant, acts as a leader” from the Assertiveness facet of Extraversion). Both items therefore are central within the larger personality structure and influence other nodes within the network. Focusing on nodes that are important according to at least two of these network statistics (item 10 [BIS]; item 55 [Reward reactivity; BAS]; item 73 [Compassion, Agreeableness]; item 86 [Productivity, Conscientiousness]; item 156 [Interpersonal conformity; Conservation values]; item 137 [Power over resources; Self-Enhancement values]), it seems that nodes related to interpersonal sensitivity (not make people angry, uncaring), emotional stability (freezes when scared) and reward striving (excited when get what I want; wealth important; lazy) are central behaviors within a personality network. These indices point towards some possible central clusters cutting across theoretical domains which may be central for understanding personality.

Indeed, when examining the assortativity coefficients implemented in the *igraph* package (Csardi et al. 2006), which indicate whether items form network clusters according to their theoretically implied dimensions (e.g., ranging between +1 where items are perfectly correlated with other items within clusters and no correlation to items from other clusters and −1 with items showing no correlation within clusters and perfect correlation with other cluster nodes), it suggested that items on average were more substantially related to items within dimensions (r = 0.360) and facets (r = 0.235) compared to other items. On average, the network structure followed theoretical expectations. At the same time, the theoretical domains varied in their internal cluster

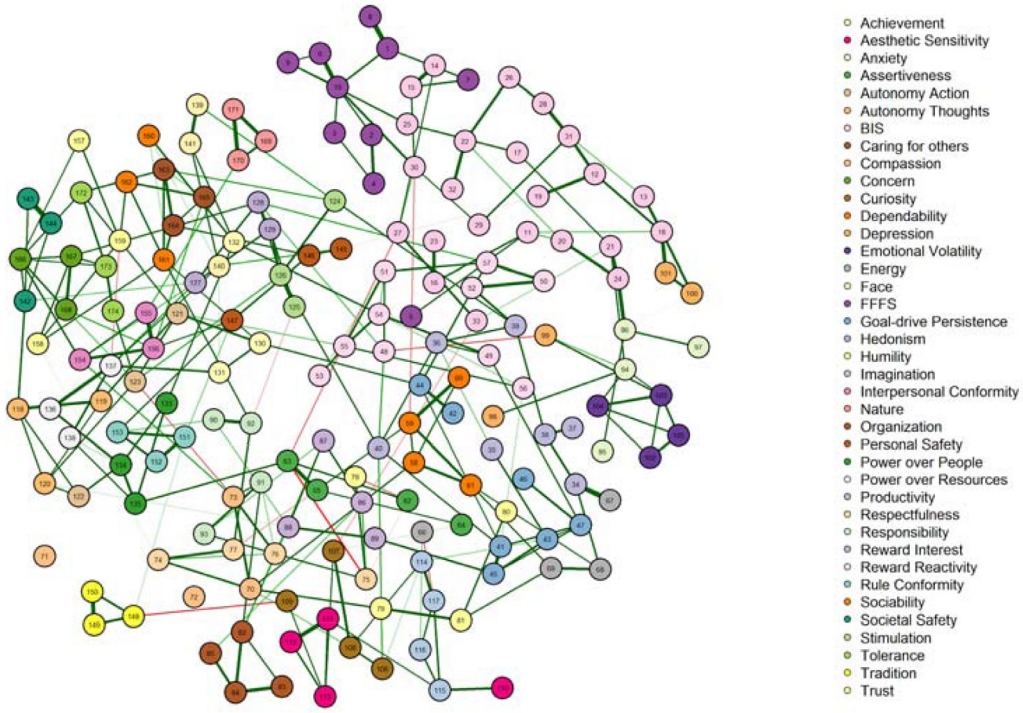

Fig. 1. Network structure of the RST-PQ, BFI-2 and PVQ-57R.

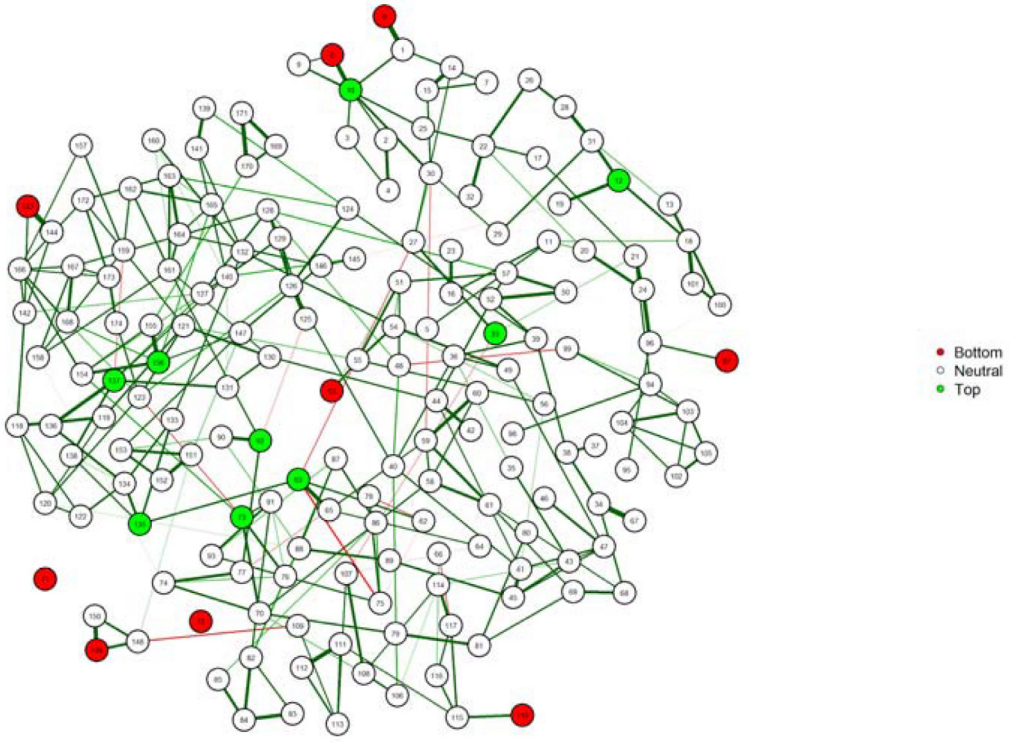

Fig. 2. Betweenness of nodes in the network.

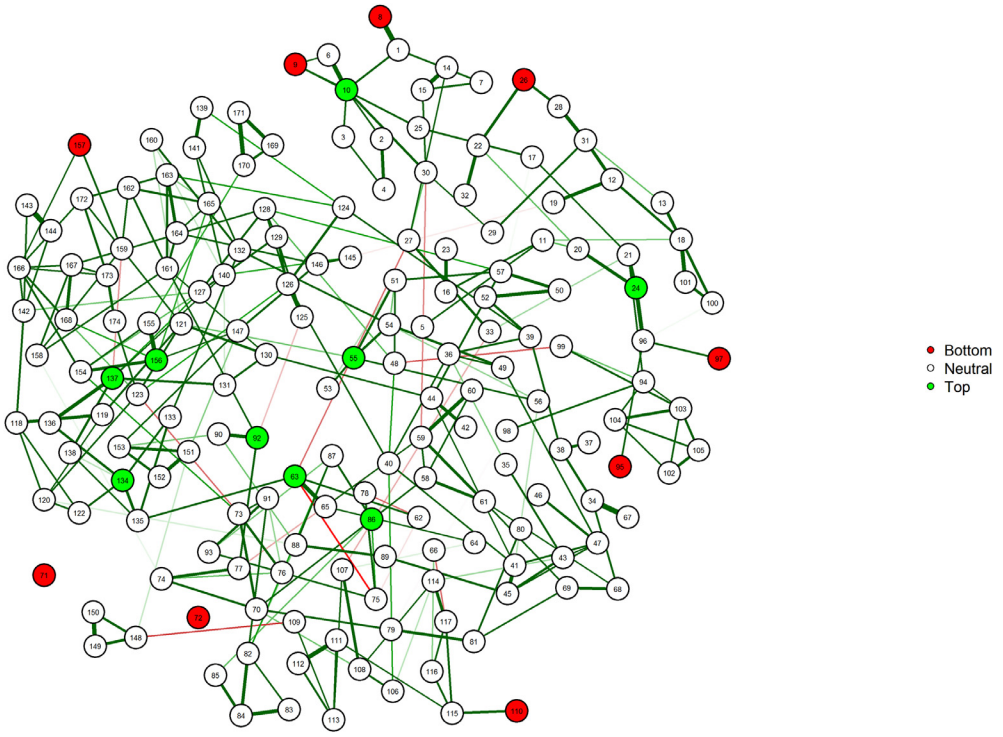

Fig. 3. Strength of nodes in the network.

consistency. A test of the weighted transitivity showed that the theoretical domains significantly differed: $F(13, 160) = 4.929$, $p < .001$, $\omega^2 = 0.227$. As can be seen in Fig. 5, the BAS components goal-drive persistence and reward reactivity, and openness to change values have higher internal consistency, whereas Openness traits, FFFS and BIS all showed lower internal consistency.

3.3. Network clusters

To better understand the underlying structure, we used Exploratory Graph Analysis (Golino & Epskamp, 2017) in the *EGAnet* package (Golino et al., 2018) to determine the optimal clustering. This exploratory approach uses a walktrap algorithm (Yang, Algesheimer &

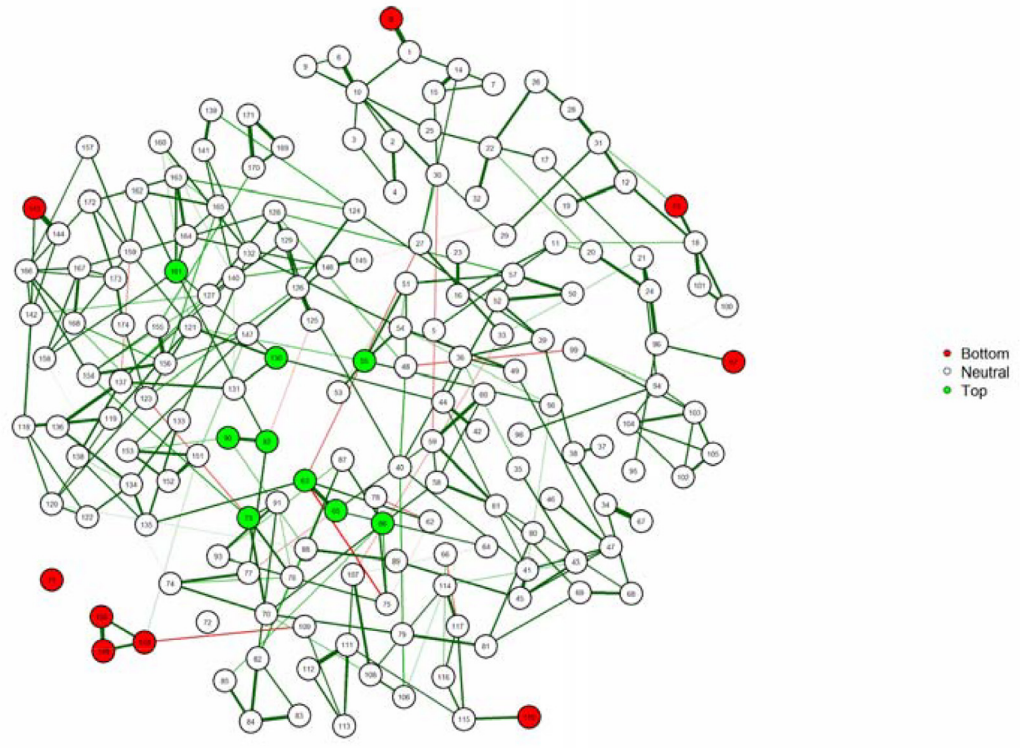

Fig. 4. Closeness of the nodes in the network.

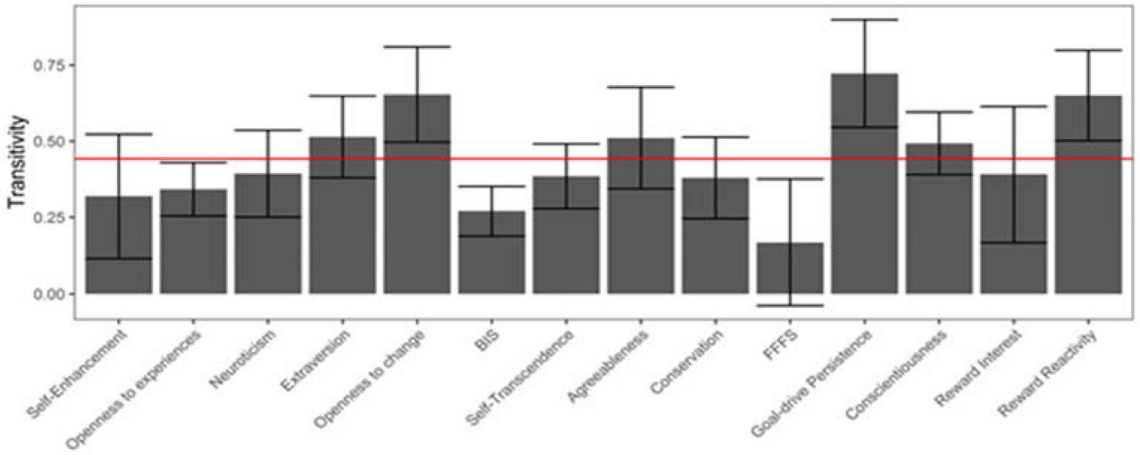

Fig. 5. Transitivity indices for the RST-PQ, BFI-2 and PVQ57R. Higher transitivity values indicate greater internal consistency of the component network.

Tessone, 2016) to find communities of nodes in the network that can be expressed as larger clusters. Simulation studies have suggested that EGA provides a more robust method for identifying central clusters that can be interpreted as possible candidates for latent variables (Golino & Epskamp, 2017). The EGA resulted in 10 clusters (see Fig. 6). A table with all items and their cluster membership is available on the osf (https://osf.io/wf26d/).

A number of theoretically expected clusters emerged. First, Neuroticism and BIS indicators merged into a single cluster (cluster 1). Similar to a previous study using NEO-PI-R data (Cramer et al., 2012), Extraversion and Agreeableness formed a joint cluster (cluster 2). However, Interpersonal conformity values and Responsibility indicators from Conscientiousness also contributed to this network cluster. Hence, these nodes all capture a strong interpersonally focused behavioral network. Socially focused values (benevolence, universalism, humility, but also opposing self-oriented values such as self-direction, achievement and hedonism) formed a third cluster. A clear fourth cluster contained all the FFFS indicators. The majority of BAS indicators as well as the Energy facet from Extraversion emerged in a fifth cluster. Openness trait indicators contributed to a clear sixth cluster. The remaining Conservation values formed a seventh cluster, whereas all but two Conscientiousness indicators made up an eighth cluster. Self-enhancement values (power over people and resources) emerged in a ninth cluster. The final cluster consisted of universalism values that are focused on protecting the environment. These clusters, except for clusters 2 and 3, showed relatively consistent and motivationally coherent networks, even though some of these clusters cut across theoretical models.

We correlated the cluster loading of each indicator with the overall node strength. The correlations were positive and significant for cluster 2 (E/A/Conformity values; $r = 0.20$, $p < .01$) and 5 (BAS/E; $r = 0.24$, $p < .01$). Therefore, nodes in these clusters have more connections

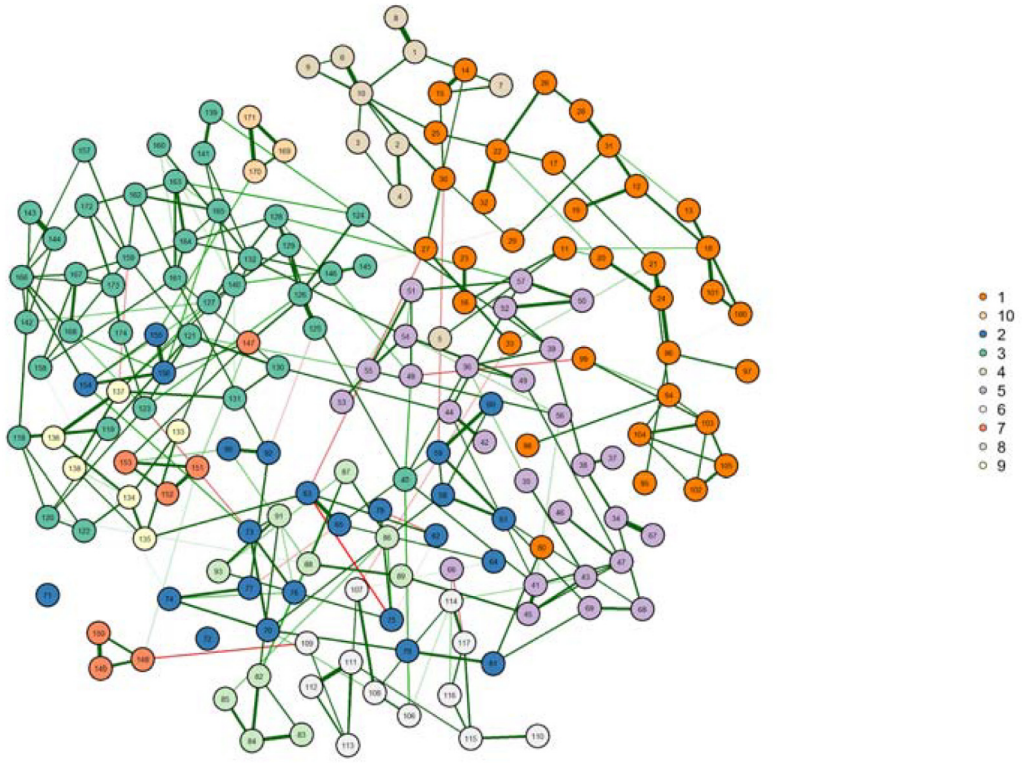

Fig. 6. The Clusters in the Network identified via Exploratory Graph Analysis.

throughout the whole network, making these nodes more central within the overall network architecture.

To more fully explore the overall relationships between all the network clusters, we conducted an MDS analysis with *smacof* package in R (de Leeuw & Mair, 2009). A stress test of random data vs our observed data suggested that 3 dimensions are sufficient to represent the cluster data (see Fig. 7). Dimension 1 was defined by behavioral inhibition/defensive behaviors (cluster 1 & 4) versus behavioral approach motivation (clusters 2, 5 & 6). Dimension 2 was characterized by conscientiousness and conservatism values (cluster 7 & 8) at one end and openness traits and universalism values (Nature protection) (clusters 6 & 10) at the opposing end, capturing a constraint vs exploration dimension. Dimension 3 differentiated self or ego-oriented self-enhancement values and Openness traits (clusters 6 & 9) from the socially oriented Extraversion/Agreeableness; and Conservative values (clusters 2 & 7).

4. Discussion

Our network analysis provides new insights how neurobiologically derived motivations, personality traits and human values form a complex motivational network structure. Our network structure showed small world network properties, suggesting that there might be a limited number of common systems that characterize the network, highlighting the importance to check redundancy across distinct measurement instruments and opening up the possibility to identify core

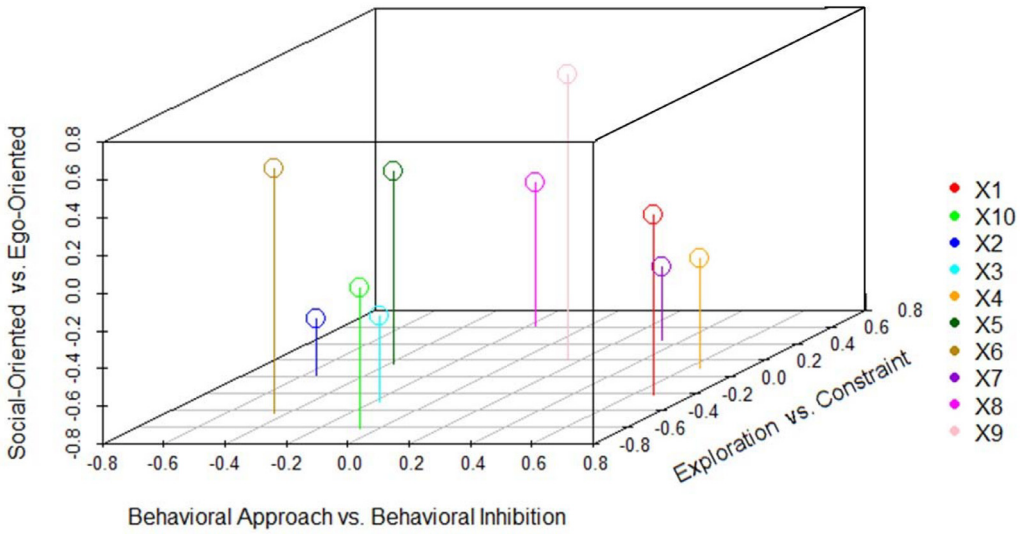

Fig. 7. Multidimensional representation of the network clusters.

behaviors of relevance for describing individuals' stable interindividual differences. As suggested by a reviewer, at a metaphysical level, the observation of small-worldness properties in personality structure implies a topological realization (Kostic, 2018): at a global systems level personality indicators appear to show coherent small world structure that is characteristic of other biological and social systems.

Within this small-world structure, we identified key nodes that might operate as both stabilizers and potential catalysts for change. For example, being dominant and acting as a leader emerged as a central node. Acting as a leader will influence a host of other nodes within the network, which indicates that leadership behavior captured by this item is strongly connected (stabilizes) a host of other behaviors of an individual, probably because behaving like a leader puts additional constraints and expectations on the behavior across different behavioral domains. To the extent that external conditions may impede an individual to perform those leadership behaviors, we would expect to see changes in a variety of other behaviors that are linked to this key behavioral node.

Network analysis provides a more nuanced insights into the motivational structure of personality which have been obscured by using factor analysis. Through examining the three-dimensional structure, it becomes possible to understand the motivational complexities of the personality network more clearly. We labelled these dimensions in light of plausible major underlying motivational systems in terms of behavioral approach versus inhibition/defensive motivation, constraint versus exploration motivation and socially versus self/ego-oriented dimensions. For example, both BIS/N and FFFS are placed at the inhibition/defensive end of dimension 1, but these clusters differ most on dimension 3 with BIS/N being more self-oriented and FFFS being more socially oriented. This distinction between BIS and FFFS supports the distinctiveness of these motivational systems as predicted by RST and adds nuance by identifying the externally focused social dimension of the FFFS, because it requires scanning and evaluating the social context for possible threats and selecting appropriate actions. At the same time, the joint cluster of BIS and N points to the strong conceptual and semantic overlap of indicators of these two concepts (e.g., BIS: 'I worry a lot', N: 'worries a lot'; BIS: 'I sometime feel blue for no good reason', N: 'Tends to feel depressed, blue', see Cooper, 2019).

Cluster 2 (E/A/Conformity) and 5 (BAS/E[*nergy*]) were clearly behaviorally approach motivation oriented, but also differed in their social orientation. Cluster 2 (E/A/Conformity) was more socially oriented whereas cluster 5 (BAS/E[*nergy*]) was more self-oriented. This clustering supports previous network studies (Cramer et al., 2012) finding similar socially oriented network clusters (merging Extraversion and Agreeableness). In order to act sociable and assert themselves individuals need to show respect that does not violate social norms (which requires attention to social values). Interestingly, nodes within this cluster showed high network centrality pointing towards the importance of socially focused behaviors for personality descriptions in general (e.g., Wood, 2015).

Conservative values (cluster 7) and Conscientiousness (cluster 8) were high on the constraint dimension but differed in that conservative values were more socially oriented (dim 3) and higher towards defensive motivation (dim 1); whereas Conscientiousness was more approach motivation oriented (dimension 1), but socially neutral (positioned close to 0 on dimension 3). This position clarifies previously observed weak correlations between conservative values and Conscientiousness (e.g., Fischer & Boer, 2015) and identifies how conservative values are socially and defensively different from Conscientiousness, even though both involve constraining behavioral impulses.

The network structure also helps to differentiate the motivational bases of values in greater detail. Self-enhancement values and Openness traits are both self/ego oriented by being placed at one end of dimension 3. However, self-enhancement values were more restraint focused (dim 2) and oriented slightly more towards behavioral inhibition/defensive motivation (dim 1), whereas Openness was positioned towards the exploration pole on dimension 2 and behavioral approach motivation (dim 1). This supports the major distinction of self-protection vs grow orientation introduced by Schwartz et al. (2012). Furthermore, the value clusters 3 and 10 were positioned towards exploration (dim 2), but with socially oriented values (cluster 3) also being somewhat more socially focused (dim 3) and motivated by behavioral approach motivation (dim 1) compared to nature-oriented values in cluster 10.

Our study was based on data from a single large sample of young adults in a WEIRD context. To better understand how personality networks are operating, it would be important to collect longitudinal data from more diverse cultural and economic samples and triangulate the self-report data with behavioral observations (e.g., Revelle, 2016). Overall, our study demonstrates the utility of network analysis to more fully explore neurobiological, trait, and human value linkages in an attempt to understand the underlying structure and organization of human individual differences. We believe this network perspective stays true to Eysenck's concern with identifying and describing behavioral regularities in context of a larger system.

Author statement

RF developed the research idea, JK wrote the analysis script, RF and JK collected the data, interpreted the results and wrote the manuscript.

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