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Reply to 'Critiques of network analysis of multivariate data in psychological science'

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In their critique of our Primer (Borsboom, D. et al. Network analysis of multivariate data in psychological science. *Nat. Rev. Methods Primers* **1**, 58 (2021))[1], Neal et al. (Neal, Z. P. et al. Critiques of network analysis of multivariate data in psychological science. *Nat. Rev. Methods Primers* https://doi.org/10.1038/s43586-022-00177-9 (2022))[2] claim that we systematically "omitted or glossed over core critiques of [network] models and methods". They outline four critiques, which apply when researchers use network models when alternative methods are more appropriate; make inferences about within-person (causal) processes based on between-person data; draw conclusions before results replicate; and use centrality indices inappropriately.

Contrary to Neal et al.'s claim, our Primer addressed these issues prominently.

Model selection

We stated that "psychometric network analysis complements existing techniques for the exploratory analysis of psychological data, such as exploratory factor analysis (which aims to represent shared variance due to a small number of latent variables) and multidimensional scaling (which aims to represent similarity relations between objects in a low-dimensional metric space)". In this comparison, the "unique focus of psychometric network analysis is on the patterns of pairwise conditional dependencies that are present in the data"; boxes 1 and 3 of the Primer illustrated distinctive differences by contrasting networks and latent variables. Of course, we agree with Neal et al. that, if a research question does not concern patterns of pairwise conditional associations, network analysis is unnecessary.

Study design

We highlighted distinctions between intra-individual versus inter-individual inferences: "[w]hen cross-sectional data are analysed … resulting topologies represent structures that describe differences between individuals", which are "not necessarily isomorphic to processes or mechanisms that characterize … individuals". Consequently, between-person networks "do not necessarily translate to intra-individual processes". However, this does not make between-person data automatically irrelevant to the individual, as Neal et al. suggest; for example, a canonical case of causal inference — that smoking causes lung cancer — was largely based on between-person comparisons[3]. In figure 3 of the Primer, we outlined techniques that go beyond between-person data, while causality was discussed in the section 'Causal inference'.

Estimation reliability

We noted that "a challenge posed by the estimation of PMRFs [pairwise Markov random fields] from multivariate data is that estimation error and sampling variation need to be taken into account when interpreting the network model" because "owing to sampling variability, one should not ordinarily expect to reproduce the network completely". We depicted and emphasized the importance of estimating instability and expected replicability in figures 7 and 8 in the Primer. Because "the degree to which the network structure replicates depends on several factors, including the network architecture itself" we provided readers with code to assess expected reproducibility for their data.

Interpretation of measures

We highlighted that "use of centrality measures [is] a topic of debate, with some papers arguing that … centrality metrics should not be interpreted in terms of causal dynamics at all". Also, we stated that "centrality metrics that concatenate paths … do not represent physical distances … and should not be interpreted as such". Finally, we urged that "more research is needed to investigate the relation between theoretical properties of possible generating models and empirical estimates of centrality".

Further critiques

Neal et al. further note that we do not cite all articles they consider important. Given our Primer's scope and the volume of the literature, we consider this unavoidable. It is both incorrect and unacceptable to suggest that this represents a 'systematic' attempt to 'omit or gloss over core critiques' in order to make methods "appear artificially robust and widely accepted". References 3 and 4 in Neal et al. concern correlation networks, which our Primer did not cover; reference 10 in Neal et al. was not published when we submitted; and Neal et al.'s reference 11 is actually cited. References 5 and 6 cited by Neal et al. are indeed among the useful papers we could have cited but note that these are derived from primary sources that we did discuss[4,5]. Reference 9 cited by Neal et al. could have been cited to illustrate problems in handling ordinal data[6], but note that these problems themselves are discussed in the section 'Network structure estimation'.

Our omission of references 7–9 in Neal et al. was intentional. One reviewer suggested that reference 7 in Neal et al. be discussed, but we rebutted that discussing this type of argument inevitably would require us to also elaborate on the trenchant critiques the relevant papers have received[6–9]. For instance, this reference contains programming errors and uses demonstrably inadequate metrics[7], while reference 8 in Neal et al., which the authors quote with approval, relies on methodology that incorrectly flags existing connections in the PMRF as being due to random chance[8]. Because of these significant concerns and because these methods have not subsequently been used in practice, we considered them outside the paper's scope.

Finally, while we appreciate Neal et al.'s effort in developing their supplementary bibliography, we disagree with the summary of some articles cited. We cannot detail our objections due to space limitations but urge readers to consult the cited articles and draw their own conclusions.

Despite these disagreements, we largely agree with Neal et al.'s recommendations. We concur that the choice of model (network, factor or otherwise) should be matched to the research question and that inferences should be based on robust findings. We agree with several critiques of centrality indices and recommend interpreting these with

appropriate caution. Finally, we partly agree with Neal et al.'s recommendation to refrain from making strong inferences about within-person causality solely from between-person data; elucidating causal structures in intra-individual psychological systems is tremendously challenging and requires evidence from a wider range of methods. We are encouraged by these points of agreement with Neal et al. regarding how network analysis can best be used to move towards this aim.

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Author contributions

The authors contributed equally to all aspects of the article. All authors reviewed and/or edited the manuscript before submission.

Competing interests

The authors declare no competing interests.