Validity of neural distance measures in representational similarity analysis

Fabian A. Soto, Emily R. Martin, Hyeonjeong Lee, Nafiz Ahmed, Juan Estepa, Kianoosh Hosseini, Olivia A. Stibolt, Valentina Roldan, Alycia Winters, & Mohammadreza Bayat

Florida International University

In representational similarity analysis (RSA), participants are presented with multiple stimuli while brain responses to those conditions, or *activity patterns*, are measured. Distances or dissimilarities between those activity patterns are measured and organized in a representational dissimilarity matrix, or RDM. The explicitly stated goal of RSA is to characterize the geometry of brain representations. Each qualitatively distinct RDM represents a corresponding qualitatively distinct geometry. A key step in RSA is to choose an appropriate measure of distance between pairs of activity patterns, as the chosen distance may influence the observed geometry. There is a large variety of distance measures that can and have been used in RSA, which opens the question: What measure should researchers use?

Practically all applications of RSA assume access to direct measures of neural activity. A more precise treatment of RSA must consider that in most cases such patterns are not direct measures of neural activity, but rather measures that have been transformed through a measurement model (the process that transforms the original activity of a neural population into the measured activity patterns in an fMRI or EEG study). The transformation imposed by the measurement model distorts the original representational geometry, and it would be useful to obtain information about what measures of representational distance are most robust to such distortions. In other words, we would like to know more about the *construct validity* of different measures of distance, or the ability of a measure to reflect the true neural distances between conditions, when it is computed on the distorted measurement space.

Here, our goal was to use simulation work to explore what measures of representational distance have the highest construct validity. In addition, we wanted to know how features of the measurement model influence the construct validity of measures of representational distance.

Our simulations assume a biologically-motivated encoding model of face shape, which was presented with a database of realistic faces (parameterized in the same shape space as the model) to obtain the "true" neural activity patterns. We used a linear measurement model, commonly used in encoding modeling of neuroimaging data, in which activity in an fMRI voxel or EEG channel is a weighted sum of the firing rates of neural channels or populations. In every simulation, we randomly sampled a different measurement model and computed RDMs in the neural and measurement spaces, using the following distances: inner product, pearson, spearman, cosine, Minkowski (with exponents 5, 10, and 50), Euclidean, city-block, variation of information, Chebyshev, Bhattacharyya, Mahalanobis (the last two with and without Ledoit-Wolf shrunk covariance). We then computed the Spearman correlation between the two RDMs as a measure of construct validity.

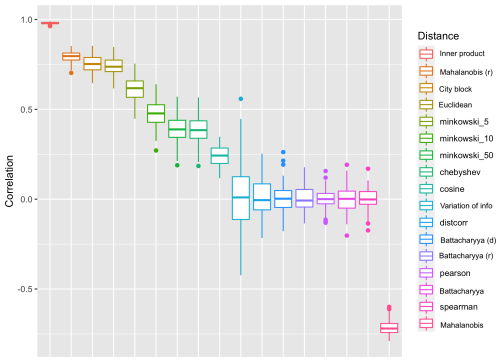

Figure 1: Results of a representative simulation

Figure 1 shows the results of a representative set of simulations, with construct validity in the y-axis and different distance measures in the x-axis, ranked according to their mean validity value. The box and whiskers plots represent the full distribution of construct validity values for each distance measure, across 100 simulations with different measurement models. It can be seen that the highest values were obtained by the inner product, followed by the regularized Mahalanobis, city-block, and euclidean measures. Other measures produced relatively poor validity values. A similar ranking of distance measures was obtained across all the performed simulations, with the inner product consistently being the best measure, despite the fact that it is not commonly used in RSA.

We determined the influence of multiple features of the measurement model on construct validity, including measurement noise, sparseness (number of zero weights per voxel), smoothness (heterogeneity of weights per voxel, so that different voxels represent information from different channels), and number of informative and noninformative voxels. Construct validity was mostly invariant to changes in sparseness and number of informative and noninformative voxels, whereas it dropped with increments in measurement noise. A reduction in smoothness produced drops in construct validity for most measures, but not for the inner product.

In sum, the dot product was not only the distance measure producing highest construct validity, but also the one that behaved best with changes in properties of the measurement model. We recommend that practitioners of RSA consider adopting it.