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When is a conjunction not a conjunction?

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Neuroimaging experiments can require conjunction inference (Price and Friston 1997). For example, it may be interesting to find brain areas that are commonly activated across different tasks. Imagine a study on working memory (WM), with a verbal WM task (task A) with a verbal control (task B), and a spatial WM task (C) with a spatial control (D). If there are areas of activation that are common to the two subtractions [A-B] and [C-D], these areas may be involved in WM independent of modality. This is a test of logical AND, finding areas where both [A-B] AND [C-D] are activated.

Price and Friston suggested the following way of getting at this problem; find areas where ([A-B] + [C-D]) is statistically significant (main effect), then remove all areas where [A-B] - [C-D] is significant (interaction effect). This was the 'interaction' conjunction test implemented in SPM96.

This method had problems. It equated the lack of statistical significance for the interaction with no effect; for example, if [A-B] is large and [C-D] is small, it is possible to have a significant main effect but not a significant interaction, and hence for the test to be positive. Alternatively both [A-B] and [C-D] could be very large but different in magnitude, giving a significant main effect and interaction, and a negative test.

In 1999, Worsley and Friston proposed a Minimum Statistic Test (MST) for conjunction. Imagine a brain region where [A-B] gives a t statistic of 1.5 and [C-D] gives a t statistic of 1.6. Alone, neither t value is convincing, but the fact that both values are quite high suggests there may be a real effect. This intuition can be formalized by taking the minimum t value from ([A-B] and [C-D]), here 1.5, and testing if this value is unexpectedly high for the minimum of two random t values under the null hypothesis. If so we conclude there is some effect over [A-B], [C-D]. SPM99 and SPM2 use the MST for conjunction analysis.

Researchers usually interpret the MST as a test of logical AND as described in Price and Friston (1997). Unfortunately this is incorrect. The problem arises because the null hypothesis for the MST is that *none* of the tasks have activated, which can be refuted if *any* task activates. Consider the t values for a single prefrontal voxel across 5 tasks, 4 WM tasks and a flashing checkerboard (FC) task. All WM tasks give a high prefrontal t value; by chance the FC gives a prefrontal t slightly < 0. The 5% uncorrected threshold for one Z is 1.64, but the 5% uncorrected threshold for the minimum of 5 Z's is -0.12, so the MST is significant even if the minimum value is less than 0. If we interpret the MST as a test of AND, we must conclude that FC activates prefrontal cortex, although it is clear that it does not.

In fact we show that a test for activation in every comparison needs to use the standard thresholds for each single comparison. Readers and reviewers should consider screening for problems related to MST.

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