DISCUSSION

PROCESS DECOMPOSITION FROM DOUBLE DISSOCIATION OF SUBPROCESSES

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Between-Task Double Dissociation is defined as a particular pattern of effects of two *factors* (manipulations) F and G on performance measures M_{T1} and M_{T2} in two tasks implemented by different complex processes. F and G might be the amounts of damage in two brain regions. The factors must influence the measures *selectively*: M_{T1} influenced by F but invariant with respect to G; M_{T2} influenced by G but invariant with respect to F. Let "$dd(M_{T1}, M_{T2}; F, G)$" denote this set of two *influence properties* and two *invariance properties*. Investigation of such cases may be called *task comparison*; what are dissociated are the complex processes used to carry out the two tasks.

I consider below a type of *within-task* double dissociation that can serve as evidence for the modularity of subprocesses of a single complex process, and is the basis of a method for *process decomposition*, an idea developed in detail in Sternberg (2001) with a dozen diverse applications; see also Sternberg (in press). Unlike task comparison, which is often used in a way that requires modularity to be assumed without test (Shallice, 1988, Ch. 11; Sternberg, 2001, Appendix A.1.), this method incorporates such a test. The inferential logic, summarized briefly below, depends on whether our measures of the subprocesses are "pure" or "composite". The comments that follow the summaries are intended to clarify some aspects of the logic; several also apply to between – task double dissociation.

Within-Task Double Dissociation: Pure Measures. Suppose we have two different measures M_A and M_B of performance in a single task. Examples include the sensitivity and criterion measures of signal detection theory (SDT) in a brightness discrimination experiment (McCarthy and Davison, 1984), and the amounts of fMRI activation in two brain regions during a number comparison task (Pinel et al., 2001). Suppose further that M_A and M_B are *pure measures* of two different parts, **A** and **B**, of the complex mental or neural process used to carry out the task. That is, $M_A = M_A(\mathbf{A})$ (M_A depends only on **A**) and $M_B = M_B(\mathbf{B})$. We wish to ask whether **A** and **B** are *separately modifiable*, such that each can be changed independently of the other. Because we can observe only the measures (not the processes themselves), the evidence used to support separate modifiability is the finding of factors F and G for which $dd(M_A, M_B; F, G)$ obtains, which also indicates (Sternberg, 2001, p. 149) that **A** and **B** are functionally distinct. Such evidence supports a theory with three components: (i) The task is accomplished by a complex process that contains two functionally distinct and separately modifiable parts (i.e., modules) **A** and **B**. (In SDT they would be the sensory and decision processes.) (ii) Module **A** is influenced by F

but not G, while module **B** is influenced by G but not F. (iii) M_A and M_B are pure measures of **A** and **B**, respectively.

Within-Task Double Dissociation: Composite Measure. Suppose we have a measure M_{AB} of performance in the task (such as mean reaction time, $\overline{RT}$) to which parts **A** and **B** both contribute: $M_{AB} = M_{AB}(\mathbf{A}, \mathbf{B})$. Let their contributions be u_A and u_B. Unlike M_A and M_B above, u_A and u_B cannot be directly observed, but it is these contributions to M_{AB} whose double dissociation is of interest: Can we find factors F and G such that $dd(u_A, u_B; F, G)$ obtains? Inferring (rather than observing) such a double dissociation requires a hypothesis (or knowledge) about how u_A and u_B combine to determine M_{AB}: a *combination rule*. For example, M_{AB} might be equivalent to the *product* of u_A and u_B – a combination rule of *multiplication* (Roberts, 1987). Or M_{AB} might be equivalent to the *sum* of u_A and u_B – a combination rule of *summation*. (One circumstance in which summation is appropriate would be if the measure was $\overline{RT}$, if **A** and **B** were arranged as stages, and if u_A and u_B were stage durations; Sternberg, 1998.) Together with the hypothesized combination rule, the four *dd* properties lead to a prediction of how factors F and G combine in influencing M_{AB}. If the prediction is confirmed, this supports a theory with three components: (i) As above. (ii) As above. (iii) Measure M_{AB} depends on contributions from modules **A** and **B** according to the hypothesized combination rule.

Comments

(1) Among the four *dd* properties, one reason the two *influence properties* are needed is that they tell us that each factor is *potent* (can alter *some* process) and that each measure is *sensitive* (can be affected by *some* factor); these conditions are required for the two *invariance properties* to be meaningful.

(2) The invariance properties require careful assessment. It is seldom recognized that failure of a standard significance test applied to an effect is not, by itself, persuasive evidence for invariance: Such a failure could merely reflect variability and low statistical power. When an effect is claimed to be null it is important in evaluating the claim to have at least an index of precision (such as a confidence interval) for the size of the effect. An alternative is to apply an *equivalence test* (Berger and Hsu, 1996) that reverses the asymmetry of the standard significance test. In either case we need to specify a critical effect size (depending on what we know and the particular circumstances) such that it is reasonable to treat the observed effect as null if, with high probability, it is less than that size.

(3) The relation between observations of the *dd* properties and a claim (theory) of modularity is like the relation between any set of observations and a theory they confirm: The observations *support* but do not *entail* the theory, and the amount of support they provide depends, among other things, on the plausibility of alternative theories also consistent with them (Howson and Urbach, 1993).

(4) With a composite measure, factorial experiments are essential (to determine how the factor effects combine); with pure measures they are not

essential but are desirable (to assess the generality, hence persuasiveness, of the *dd* properties, and also to exclude certain single-process accounts; Dunn and Kirsner, 1988).

(5) Triple and higher order dissociations can show that a complex process contains more than two modules; achieving a two-fold partition of the process should be regarded as only a first step (Sternberg, 2001, Sec. 1.3).

(6) The goal of process decomposition is to divide the complex process by which a particular task is accomplished into modular subprocesses. Changes in factor levels are intended not to produce "qualitative" changes in the complex process (such as adding a new operation or replacing one by another) which change the "task", but just "quantitative" ones that leave the task invariant. While unlikely to lead to erroneous inferences, qualitative changes can reduce the likelihood of discovering modules. (This can occur, for example, if a change in the level of one factor replaces or adds an operation influenced by another.) One kind of evidence for qualitative task invariance is the pattern of factor effects: For each factor, each change in level should influence the same operations and leave the same other operations invariant. The usefulness of such evidence is one of several reasons for using factors with more than two levels (Sternberg, 2001, Appendices A.2.1, A.9.2), but few studies have done so.

(7) In the real world, the data that support a claim such as «*dd* (M_A, M_B; F, G) obtains» are imperfect. Apart from the statistical issues mentioned in (3), above, it has to be shown that the effects of F on M_A and of G on M_B are convincingly large, and that the effects of G on M_A and of F on M_B are convincingly negligible. What is convincing depends in turn on the potencies of the factors and the sensitivities of the measures. Some discussion of how these considerations might guide the creation of an *index of double-dissociation* can be found in Sternberg (2001, Appendix A.11.2).

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