

How Many Resources and How to Identify Them? Commentary on Boles et al. and Vidulich and Tsang

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One goal of human factors is to identify theory-based mechanisms of human performance that can account for meaningful performance differences in real-world tasks and settings. Boles, Bursk, Phillips, and Perdelwitz (2007, this issue) set out to do this by demonstrating that mechanisms of multiple resources, as assessed by a method different from the more conventional multiple resource model with which I have been associated (Wickens, 1980, 1984, 2002), can account for differences in dual-task interference between complex tasks that can generalize to real world tasks. (In the preceding characterization of their research, I focus only on Experiment 2, for reasons I will describe later.) Their research provides data that appear to support this generalization.

Vidulich and Tsang (2007, this issue) offer a number of criticisms of the research, with two in particular focusing on (a) the fact that sequential processing of two tasks, resulting because of widely separated displays and discrete responses, may limit the contributions of multiple resources to time-sharing in the paradigm chosen; and (b) concerns about the structure of the three tasks in Experiment 2 – one pair mandating more continuous demands and therefore concurrent processing, and the other two pairs probably prohibiting it. They suggest that this feature could readily account for the observed data, thereby eliminating the need to postulate multiple resource mechanisms. Boles and Phillips (2007, this issue) in turn argue in defense that sequential processing is common in most time-sharing applications and that asynchronous processing “was considered to more closely mimic dual tasks as used in the real world” (p. 51).

Although both of Vidulich and Tsang’s (2007) concerns have some merit, I also believe that the data are consistent with a multiple resource inter-

pretation, and so I will not reemphasize their concerns. Rather, I wish to highlight the importance of six theoretical and methodological issues of applied attention research, which the current paper brings to the forefront. In doing so, I hope to extend the message of the experimental research reported in ways that the authors may not have highlighted.

Issue 1. Total demand versus resource similarity. In both my older (Sarno & Wickens, 1995; Wickens, 1980, 1984, 1991) and more recent (Horrey & Wickens, 2004; Wickens, 2002, 2004) writings on multiple resource theory, I have emphasized the separate and independent contributions of three components to predicting dual-task interference: (a) the total demand for resources (i.e., the difficulty or workload of the component tasks), (b) the similarity between the two tasks, and (c) the resource allocation policy. The third is not a concern in the current study. In my approach to modeling (Wickens, 2002), I have treated the first two components as independent and, possibly, based upon very different mechanisms of human information processing. Thus I applaud Boles et al. (2007) for developing an original scaling mechanism to characterize each of these two on the basis of subjective ratings: total demand on the one hand and the two scales of profile and overlap similarity on the other. Their conclusions, however, in establishing the relative contributions of each, must be accepted with considerable caution for reasons to be described in Issue 5.

Issue 2. Parallel versus sequential processing. As noted, Vidulich and Tsang (2007) take some issue with the extent to which the paradigm employed by Boles et al. (2007) actually induces the parallel (concurrent) processing situation for which any resource-sharing theory (single or multiple) is most germane. Although I agree in

part with this concern, I also adopt a somewhat different perspective, accepting Boles et al.'s (2007) fourth argument, that the pattern of data – revealing that similarity does influence the performance decrement – is adequate evidence to assume that some degree of parallel processing was ongoing between task pairs. Furthermore, the categorized differences between verbal (lexical) demands of one task and spatial demands of the other two constitute a plausible mechanism for accounting for such differences in concurrent processing. However, I would like to go a step further and suggest that the distinction between concurrent and sequential processing in dual-task processing is often fuzzy, in that even when two complex tasks are “performed” in series, it is often the case that memory-induced residuals from one task can carry over and inhibit performance of a subsequent task, particularly when the material for the two tasks is similar and instructions induce rapid performance and interleaving of both. Indeed similarity-based confusions in working memory (e.g., Baddely, 1986; Wickens & Hollands, 2000) represent a strong contributor to variance in performance. Thus the more general message here is that demonstration of two similar tasks, interfering more because of similar processes, has important human factors implications even if it is impossible to fully establish the extent to which the processing of both is ongoing simultaneously or is in rapid sequential alternation.

Nevertheless, the Vidulich and Tsang (2007) critique that much of the processing in the dual-game paradigm is sequential appears to be valid, and it constrains the generalizability of the current results to real-world time-sharing, as I discuss in Issue 6.

Issue 3. Correlational versus dichotomous approaches to validation. Boles et al. (2007) have chosen a correlational approach to model validation, by which task pairs are assessed on two dimensions (subjective ratings and performance decrements) and correlational measures are used to establish the degree of association. The constraints on any such correlational technique are that the degree of association is limited by the range of both variables that are input to the correlation. If the range of either variable is small, then the correlation will be small (the phenomenon classically known as “restriction of range” in predictive validity research). In this particular case, it is likely that the small correlation found between

total demand and interference in Experiment 2 is a consequence of the fact that all three tasks are of relatively high and similar demand. This limited range of demand value stands in particular contrast to the wide variety of actual demands in tasks confronted by users outside the laboratory. Thus the authors need to be more cautious in their general assertion, “The outcome strongly indicates that total resource demand on the system is less important than resource-by-resource correspondences between tasks” (Boles et al., 2007, p. 42). It would have been easy to select a set of tasks for evaluation with vastly different measures of single task difficulty but the same resource structure, and this selection would have revealed a pattern of results opposite from those obtained. (Interestingly however, Sarno & Wickens, 1995, using a very different approach, did find that structural similarity accounted for more variance in time-sharing efficiency than did task demand, a conclusion consistent with that of Boles et al., 2007.)

Issue 4. Process-based versus physiologically based characterization of resources: The issue of parsimony. Boles et al. (2007) make quite explicit their claims that every mental process possesses a (unique?) resource, as justification for the large number of resources postulated; there is certainly merit to this assertion. However, the approach I have taken to multiple resources has been somewhat different. In the interests of parsimony (Wickens, 2002), I define as separate resources only those entities that meet three criteria:

- The dichotomies defining resources (verbal versus spatial, auditory versus visual, perceptual/cognitive versus response, and focal versus ambient vision) all have a physiologically identifiable manifestation within the brain.
- Each dichotomy has proven to account for interference differences in real-world tasks and/or contexts.
- Each dichotomy is one that has meaningful and relatively easy-to-implement implications for system designers who wish to make changes that will reduce resource competition (e.g., altering a display from sight to sound or from text to graphics).

Certainly the approach of Boles et al. (2007), based heavily on only the second of these three criteria, is scientifically defensible; however, if in the process the number of “things” that are labeled *resources* proliferate beyond the level at which designers can readily implement changes to reduce resource overlap, the value of the approach to human factors diminishes. In this regard, it

would be important for the authors to demonstrate the extent to which the 17 dimensions used in the current application provide value (i.e., predicted variance) above and beyond the simpler multiple resource model that I have proposed (eight resources: two on the two ends of each dichotomous dimension).

Issue 5. Expert identification versus performer identification of resource categorization. Boles et al.'s (2007) demonstration of the validity of performer (participant/worker) categorization of the resource composition of component tasks is of value. Expert ratings have traditionally been used in other resource demand approaches (e.g., Aldrich, Szabo, & Bierbaum, 1989) but not explicitly for multiple resource identification. Indeed, one criticism sometimes offered by users of the four-dimensional multiple resource model is that coding is typically done only by the expert model user. Sound demonstration that nonexperts generate meaningful ratings, such as provided by the current data, will add to the robustness and utility of such techniques.

Issue 6. Basic versus applied research. Engineering psychology research has always been carried out amid a tension between the desire for control, which often imposes unrealistic task simplifications or constraints on participants, and the desire for generalizability, which often imposes complexity that diminishes control. Although I feel that the paradigm of Experiment 1 is too controlled to contribute much to human factors knowledge, it seems evident how each of the three tasks used in Experiment 2 could be readily mapped onto extralaboratory activity.

This being said, however, the current research, augmented by Vidulich and Tsang's (2007) critique and Boles and Phillips's (2007) response, bring to the fore several issues. On the one hand, the dichotomy between "theoretical versus applied research" implicitly suggested in the Boles-Phillips response is, in my opinion, a false dichotomy that is often inappropriately raised. This is because either basic or applied research can be equally theoretical (or atheoretical, for that matter). Indeed, in the current case, both the previous multiple resource versions with which I have been associated and the current MRQ version are equally grounded in solid theory.

On the other hand, however, the contrast of "basic versus applied" research is much more germane and leads me to highlight two cautions

in accepting the generalizability of the current research to real-world applications. First, Boles and Phillips (2007) argue that "the asynchronous design...was considered to *more closely mimic dual tasks as used in the real world*" [italics added] (p. 51). This assertion is debatable. There are indeed many cases asynchronous behavior (Liao & Moray, 1993) in the real world, well modeled by minimal parallel processing, but this "real world" is also filled with examples of concurrent performance and parallel processing. A small sampling includes vehicle control and collision monitoring while conversing, planning while walking, walking while reading, cooking while listening to a news broadcast, writing while listening to music, rehearsing while climbing, and note taking while processing a lecture. It is noteworthy that a particular feature of many of these is the *absence* of visual inputs on both tasks. However, it is precisely these circumstances for which multiple resource models are most relevant. Therefore, the current emphasis on dual visual perceptual processes (14 of the 17 resources), highlighted by the MRQ approach, seriously underrepresents that vast array of multitask situations for which multiple resources are applicable.

Second, independent of the degree to which their chosen task pairs in Experiments 1 and 2 allow or prohibit concurrent processing (an issue debated in the three foregoing articles), Boles et al. (2007) have not fully demonstrated how their laboratory tasks can be directly mapped onto task pairs in some real-world "work environment." Ideally, this mapping will be the next step in their research – for example, choosing real-world processing of two channels of information in an air traffic control or emergency management display that would map directly to dimensions of the MRQ and showing the predictive validity of the MRQ with those real-world instantiations of the dimensions in question. Only then can the true relevance of the MRQ approach to real-world behavior be fully established.

In conclusion, the work reported is of importance, and certainly lays out some critical issues to be considered as applied researchers still struggle with the breakdowns in multiple task performance (cell phone use and in-vehicle technology emerges as a critical concern in this area). Its presentation also suggests both theoretical and methodological issues in human factors work, issues I have tried to highlight in this commentary. I hope

that this research paves the way for further examination of these important issues.

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