subsystems or buffers of short- and long-term memory systems. This description of brain activity results from observing patterns of brain activity under various conditions. In their view, a variety of patterns, activated by fewer systems, accounts for short-term memory as well as for long-term memory processes.

This economy in scientific description may mimic the economy that evolution may have selected for natural events. Allowing many permutations by a few entities, perhaps based on algorithms yet to be described for brain activity, is most elegantly seen in DNA coding. The principle of parsimony functions at the language level of science, as it does at the level of observable events in nature, selected by evolutionary processes. Phylogeny provides for the susceptibility of various patterns to occur in ontogeny under various conditions. In other words, an algorithm pervading functions selected by evolution, may go like this: Multiple patterns in few structures, to account for occurrence under multiple conditions, are more economical than multiple structures to account for a variety of patterns. However, to verify this will take more research on the conditions under which many memory functions occur, including more research on more memory proceduralist accounts of the kind provided by Ruchkin and colleagues.

Within their discipline, Ruchkin et al.'s replications across data figures, across many conditions, and across research results by other investigators, seem to lend convincing support to an economic model of brain activity in memory processes. On an interdisciplinary level, proceduralist or activation models in other memory-related processes analogously support Ruchkin et al.'s model. Grote (submitted) discusses an experimental model of self-instruction as a form of memory mediation, in which procedures can control and account for problem-solving facilitated by prompted self-instruction, sometimes needing procedures for prompting commitment to spend attention to and to remember self-instruction. That model requires no special status for a "self," and it requires no separate cognitive-behavioral or neuropsychological structure or meta-structure to be invoked for more memory, in order to have more economic functioning, in problem-solving. The present commentary welcomes Ruchkin and colleagues' findings as a contribution to clarifying a number of concepts related to memory, including self-control, self-regulation, and especially self-instruction, and for purging the need for extra systems from cognitive-behavioral conceptualizations.

A few additional bits of information, however, would have been useful in Ruchkin et al.'s report – especially some relevant for cognitive-behavioral developmental models. Such models regard the modality-specificity of verbal and visuo-spatial dimensions under different conditions of development to be of importance (e.g., Jones 1973 on the visual, Zeaman & House 1979 on two- and three-dimensional stimuli). Hence, I would have liked to see some information on the age and educational level of participants. I also wondered whether they were different or same cohorts of participants that were represented in the various data figures.

A few more (benign) points of criticism: I missed seeing a figure on semantic *relatedness* (sect. 3.7) for comparison with Figure 10 for semantic *unrelatedness* (sect. 3. 7). More information about the unpublished research (cited at the end of sect. 3.2 and in sect. 3.4) – and with which colleagues – could have been given in a note; along with further clarification of the Ruchkin (1997a; 1997b) studies, including mention of the colleagues involved here.

Finally, it would be instructive if "Phreneurology" measurement, such as described in the Appendix, could be schematized in a figure, as it is relevant to and referenced in nearly each figure of the target article. (I deliberately call the measurement "phreneurology," tongue in cheek, because it is peculiarly reminiscent of old phrenological concepts for mapping scalp topographies.)

# Another artificial division – and the data don't support it

Martin Heil,[a] Frank Rösler[b], and Bettina Rolke[c]

[a]Institute of Experimental Psychology, Heinrich-Heine-University, 40225 Düsseldorf, Germany; [b]Experimental and Biological Psychology, Philipps-University, 35032 Marburg, Germany; [c]Institute of Psychology, Eberhard-Karls-University, 72072 Tübingen, Germany.
Martin.Heil@uni-duesseldorf.de    roesler@staff.uni-marburg.de
Bettina.Rolke@uni-tuebingen.de

**Abstract:** Evidence for the contribution of the neocortex to memory is overwhelming. However, the theory proposed by Ruchkin et al. does not only ignore subcortical contributions, but also introduces an unnecessary and empirically unsupported division between the posterior cortex, assumed to represent information, and the prefrontal cortex, assumed to control activation. We argue instead that the representational power of the neocortex is not restricted to its posterior part.

Arbitrary divisions are quite popular in science, and, because they help to structure the respective fields, they might make sense for a certain period of time, even if they ultimately turn out to be wrong. So, for example, quite a substantial amount of research was driven by the idea that short-term and long-term memory are realized by distinct storage systems (Atkinson & Shiffrin 1968). In accordance with a number of previous theories based in the fields of Experimental Psychology (e.g., Anderson & Bower 1973), in Cognitive Neuroscience (Fuster 1997), and in Neural Network Modeling (e.g., McClelland et al. 1995), respectively, Ruchkin et al. want to repudiate the existence of this division. Instead, short-term memory is understood as the activated part of long-term memory.

So far so good, but we nonetheless see a problem in the target article. We do not want to discuss whether one more theory stating the nondistinction between short-term and long-term memory was needed. In the same way, we do not want to dispute the experimental quality of the studies presented – even though in almost all cases the comparisons are confounded by differences in the overall difficulty of the conditions examined. (Therefore, the data do not allow for unequivocal interpretations.) Instead, we want to focus on the theoretical contributions of Ruchkin et al.

The main problem we see is that the authors introduce a new artificial division, namely, between the posterior cortex (the region where the memory representations are assumed to be located) and the prefrontal cortex (where an "attentional pointer system" is assumed to control and maintain the activation in the posterior cortex). For the sake of clarity, we break this idea down into three parts in order to illustrate its implications. In addition, we comment on the basic assumptions behind the artificial division.

***According to Ruchkin et al., the cortical memory capabilities are assumed to be restricted to the posterior cortex.*** There is, however, quite substantial empirical work supporting the idea that the anatomical basis for memory is *not* restricted to the posterior cortex. To give just a few examples, it is assumed that motor representations are stored in the motor cortex and probably in the supplementary motor area (see, e.g., Nyberg et al. 2001), which are both *not* part of the posterior cortex, and that these representations are reactivated when the motor information is retrieved (Heil et al. 1999). Similarly, the premotor cortex is also activated when manipulable objects, as opposed to non-manipulable ones, are maintained in working memory (Mecklinger et al. 2002). Recent evidence also shows that over anterior scalp areas different event-related potential (ERP) topographies are evoked, if either verbs or nouns are accessed (Khader et al. 2003). Finally, the role of the left frontal cortex (certainly not a part of the posterior cortex) in the representation of verbal and/or semantic information in both short-term and long-term memory tasks cannot be underestimated (see, e.g., Heil et al. 1996; Paulesu et al. 1993). To sum all this up, the idea that memory representations are restricted to the posterior cortex does not survive empirical tests – leaving aside the fact that Ruchkin et al. don't even specify what the "posterior" cortex does actually embrace.

***Control and maintenance of activation in memory are assumed by Ruchkin et al. to be done by the prefrontal cortex.*** Although there is support for this idea regarding the function of the prefrontal cortex, the data, in fact, suggest a domain-specific regional organization of the prefrontal cortex (e.g., Goldman-Rakic et al. 2000). Because of the limits in the spatial power of the EEG, however, Ruchkin et al.'s own data do not address this point satisfactorily. Therefore, this assumption of Ruchkin et al. remains quite nebulous. Fortunately, other elaborated models based on high-quality data (e.g., D'Esposito et al. 2000) already exist showing that the prefrontal cortex is not a functionally unitary entity.

***The idea of a hippocampal contribution, or more generally, subcortical contributions to memory, is ignored.*** It is quite obvious that a theory of memory has to incorporate the contribution of the hippocampus (see, e.g., Squire 1992). O'Reilly and Norman (2002), for example, present a complementary framework for the hippocampal and the neocortical contributions to memory. And, of course, memory functions critically depend on additional subcortical structures, even if one were to ignore the emotional embedding of information (see, e.g., Markowitsch 2000). It is true that the EEG has a somewhat blind spot for the neural activity in subcortical structures, but that does not justify the theory itself suffering from that same shortcoming.

So what is left of the theory proposed by Ruchkin et al. is (1) the idea that short-term memory should be understood as the active part of long-term memory, (2) the idea that content-specific representations in the neocortex are activated when information is processed, stored, and retrieved, and (3) the idea that the prefrontal cortex plays an important role in some kind of control of activation. In fact, none of this is new (see, e.g., Rösler & Heil 2003, for an overview of existing theories). The artificial division between posterior cortical areas that do represent information and prefrontal cortical areas that do not represent information is new, at best, but should not be adopted in cognitive neuroscience as long as no more convincing data are presented.

# Temporal lobe speech perception systems are part of the verbal working memory circuit: Evidence from two recent fMRI studies

Gregory Hickok[a] and Bradley Buchsbaum[b]

[a]*Department of Cognitive Science, University of California, Irvine, CA 92697;* [b]*NIMH Clinical Brain Disorders Branch, National Institute of Health, Bethesda, MD 20892.* **gshickok@uci.edu     www.lcbr.uci.edu**

**Abstract:** In the verbal domain, there is only very weak evidence favoring the view that working memory is an active state of long-term memory. We strengthen existing evidence by reviewing two recent fMRI studies of verbal working memory, which clearly demonstrate activation in the superior temporal lobe, a region known to be involved in processing speech during comprehension tasks.

The argument favoring the hypothesis, that working memory is an active state of long-term memory, is relatively weak in the verbal domain. The weakness stems from the following observation: Fronto-parietal areas have been implicated in verbal working memory, both in previous hemodynamic imaging studies (Smith & Jonides 1997) and in the current article, yet these areas are not implicated in the auditory perception/comprehension of verbal material. For example, studies of passive listening to speech stimuli – which no doubt activate long-term memories (and/or perceptual processing systems) for verbal material – have implicated superior temporal regions bilaterally, not frontal or parietal cortices (Hickok & Poeppel 2000). Lesion evidence similarly implicates the superior and middle temporal gyri in the perception and comprehension of speech (Dronkers et al. 2000; Hickok & Poeppel 2000). If verbal working memory is an active state of systems involved in representing/processing speech, we expect the supe-

rior temporal lobe to be regularly implicated in auditory verbal working memory, yet it is it not.

Two recent fMRI studies conducted in our lab resolve this apparent contradiction. These studies used a novel paradigm, in which, on each trial, subjects were presented with acoustic speech information, which they then rehearsed subvocally for an extended period of time (15 to 27 seconds in different experiments), followed by a rest period. Analysis focused on identifying regions that were responsive *both* during the perceptual phase and the rehearsal phase of the trial. The logic of this design was driven by several factors, one of which was the behavioral demonstration that irrelevant acoustic information interferes with immediate serial recall (the irrelevant speech/sound effect, Jones & Macken 1996; Salamé & Baddeley 1982), suggesting that acoustic information has obligatory access to short-term storage systems. From a neurophysiological standpoint, this means that a region supporting short-term storage should be responsive not only to maintenance of acoustic information, but also to the simple perceptual presentation of that information (Becker et al. 1999), hence the focus on regions with combined perceptual + rehearsal response properties.

Using this technique, and in two separate studies (Buchsbaum et al. 2001; Hickok et al. 2003), we identified a network of regions with these response properties. This network included two frontal regions, Broca's area and a premotor site, consistent with previous studies (Smith & Jonides 1997), and thought to be involved in articulatory rehearsal. But relevant to the present discussion, we also found two locations in the superior temporal lobe, one in the superior temporal sulcus (STS) bilaterally, and one along the dorsal surface of the left posterior superior temporal gyrus, that is, in the Sylvian fissure at the parietal-temporal boundary (an area we have called Spt). Figure 1 presents a group-averaged activation map from a meta-analysis of these two studies, showing the temporal lobe activation sites (as well as the frontal activation). The STS locations (bilaterally) clearly map onto regions that have been implicated in auditory speech perception/comprehension (Hickok & Poeppel 2000), thus providing strong support for the hypothesis that verbal working memory is an active state of more fundamental processing/representation systems. Nonlinguistic auditory stimuli (music) produce a very similar activation pattern in the same task (Hickok et al. 2003), suggesting that this network is not linguistic-specific; a result consistent with behavioral data (Jones & Macken 1996). Previous studies may have missed these temporal lobe activations: (1) because of anatomical variability in this region leading to partial averaging effects, (2) because subtraction conditions involved acoustic controls, or (3) in the case of the electrophysiological work, because the activity buried in a deep fissure and possibly on opposite banks of that fissure, may not be visible to EEG methods.

Although the STS activations are consistent with sites involved in perception/comprehension of speech, the functional role of the parietal-temporal activation (area Spt) is less obvious. Damage to
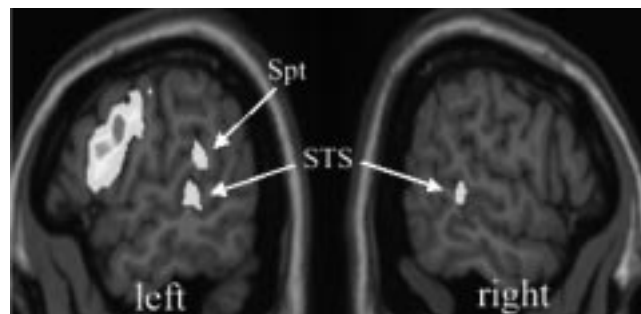


Figure 1 (Hickok & Buchsbaum). Cortical regions showing fMRI activation both during the auditory perceptual and (covert) rehearsal phases of a verbal short-term memory task (pooled data from 10 participants).