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Word versus task representation in neural networks

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Abstract: The Hebbian view of word representation is challenged by findings of task (level of processing)-dependent, event-related potential patterns that do not support the notion of a fixed set of neurons representing a given word. With cross-language phonological reliability encoding more asymmetrical left hemisphere activity is evoked than with word comprehension. This suggests a dynamical view of the brain as a self-organizing, connectivity-adjusting system.

Pulvermüller's (Braitenberg & Pulvermüller 1992) theory of language based on the Hebbian principle of associative learning is brilliant. This principle implies the engagement of cell assemblies, which include neurons in cortical areas where correlated neuronal activity occurs during learning. Words would be represented by distributed cell assemblies that form during learning and are comprised of those neurons that then show correlated firing. For example, a word referring to an object that is usually perceived visually would then be represented by a cell assembly with members beyond the perisylvian region, including the occipital lobes and the inferior temporal region. The representation of a verb referring to actions will include neurons in motor and premotor areas related to the execution of the body movements to which the verb refers.

Though satisfying, this theory is so perfect that it can be shaped to explain whatever experimental observations are being made; hence it is difficult to falsify. The following experimental example demonstrates the difficulties one encounters when translating some of Pulvermüller's theoretical considerations into experimental predictions.

We measured event-related potential correlates of phonological encoding as compared to lexical access and semantic categorization in 14 German and 14 Italian subjects (Angrilli et al., submitted). Within a two-stimulus reaction time paradigm, stimulus pairs had to be matched with respect to semantic identity (word-picture) in a word comprehension task or with respect to the phonological (word) representative of the picture of objects in a rhyming task. The slow negative potential prior to the second stimulus was considered an electrocortical correlate of the activation produced by the presentation of the first stimulus. As illustrated in Figure 1, this activation is specific to the language-related task and not specific to the words presented. With cross-language reliability, we found that whereas phonological encoding (rhyming) evoked a more pronounced left- than right-hemispheric negativity, little asymmetry was found in the word comprehension task.

From these and other studies (e.g., Eulitz et al. 1996), we con-

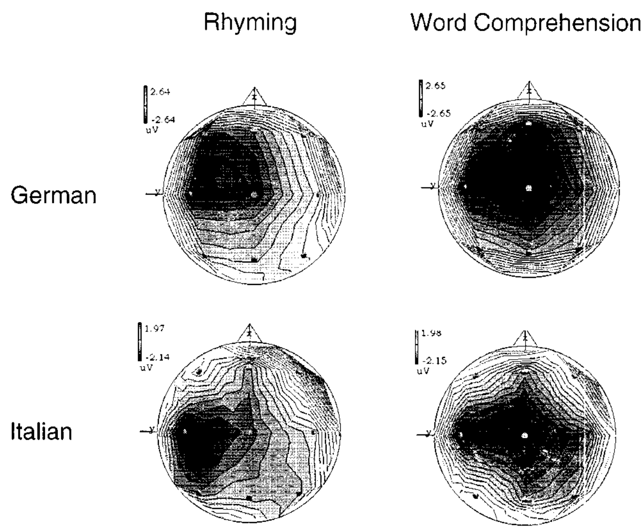

Figure 1 (Elbert et al.). In the phonological encoding task of the German experiment, two pictures of objects were presented with an ISI of 2 sec. The subject's task was to decide by pressing a button whether the words represented by the picture rhymed. For the Italian sample, two words were presented; for the second of these the subject had to decide whether the words were phonologically similar (rhymed). In the word comprehension task a 1-s word presentation was followed after 2 sec by a picture of an object. The subject's task was to decide whether the picture matched the word.

The maps show the change from baseline prior to the presentation of the second word, that is, while the representation of S1 was active. Because the same words were presented in both tasks, unique word representation would predict identical scalp distributions for rhyming and word comprehension. Rhyming produced an asymmetric map, however, irrespective of whether a picture (German study) or a word (Italian study) was presented.

clude that the neural network activated by the presentation of a word does not have a unique representation, but depends on the level of processing invoked by a specific task. One experimental condition may enhance word representations on a semantic level (as in the word comprehension task) and another condition on the word form level (as in the phonological encoding task). Yet another task might activate word representations on their syntactic level (Levelt 1989). [See also Levelt: "A Theory of Lexical Access in Speech Production" *BBS* 22(1) 1999.] Depending on the context, the same word or percept can activate a lateralized cell assembly in the left hemisphere, as in rhyming or a distributed network (e.g., in word comprehension).

This illustrates the limits of approaches based on Hebb's rule: It seems impossible to define which neurons are included in a cell assembly representing a word and which are not. A network may operate in different modes, recruiting one set of neurons in a reverberating circuit for a word representation in one task and another set on another task. Accepting this would render the concept of a fixed set of neurons representing a given word useless.

If the brain is viewed as a dynamic, self-organizing system that permanently adjusts the connectivity among its excitable units and can even alter its numbers, then it is not the representation of words, objects, actions, and so forth that would be localized, but the activity related to a specific task performance. Somatosensory perception would concentrate activity in the postcentral gyrus, in posterior parietal cortex, and SII; rhyming would center activity in the left hemisphere perisylvian region, whereas word comprehension would require widespread, bilateral activity.

This point is further illustrated by research on cortical representational plasticity (Bunomano & Merzenich 1998; Elbert & Flor, in press): modified by task and experience, the cortex can preferentially allocate neural elements to represent and process any relevant input source. The somatosensory cortical representational map is not the body surface, but is similar to the "language" the brain uses to process sensory experience. Like the dynamic adjustments of language, the map may adapt to different sensory experiences and demands. One and the same neural network can store different concepts, operating in different modes; that is, different "languages" may be coded in the synaptic weights of the network. A network in primary representational zones may respond with one spatial pattern of activity in one condition and a different pattern in another (Birbaumer et al. 1997).

Similarly, a word might have one representation in a syntactic task but another during semantic processing. Hence Pulvermüller's view might not be sufficient to describe brain functioning. It may adequately model one given set of data but fail to explain another one. We may ultimately have to adopt a position akin to the one in quantum mechanics where for an electron, the model of a particle can be adequate to explain one set of data and the model of a wave might be needed to explain observations under different experimental conditions. The concept of a word representation may explain data only from certain distinct, very simple paradigms; the concept of task-dependent organization or the interaction between the two views may be needed in experiments that go beyond the framework presented by Pulvermüller.