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Commentary on **Friedemann Pulvermüller (1999). Words in the brain's language. BBS 22(2)253–336.**

Abstract of the original article: If the cortex is an associative memory, strongly connected cell assemblies will form when neurons in different cortical areas are frequently active at the same time. The cortical distributions of these assemblies must be a consequence of where in the cortex correlated neuronal activity occurred during learning. An assembly can be considered a functional unit exhibiting activity states such as full activation ("ignition") after appropriate sensory stimulation (possibly related to perception) and continuous reverberation of excitation within the assembly (a putative memory process). This has implications for cortical topographies and activity dynamics of cell assemblies forming during language acquisition, in particular for those representing words. Cortical topographies of assemblies should be related to aspects of the meaning of the words they represent, and physiological signs of cell assembly ignition should be followed by possible indicators of reverberation. The following postulates are discussed in detail: (1) assemblies resembling phonological word forms are strongly lateralized and distributed over perisylvian cortices; (2) assemblies representing highly abstract words such as grammatical function words are also strongly lateralized and restricted to these perisylvian regions; (3) assemblies representing concrete content words include additional neurons in both hemispheres; (4) assemblies representing words referring to visual stimuli include neurons in visual cortices; and (5) assemblies representing words referring to actions include neurons in motor cortices. Two main sources of evidence are used to evaluate these proposals: (a) imaging studies focusing on localizing word processing in the brain, based on stimulus-triggered event-related potentials (ERPs), positron emission tomography (PET), and functional magnetic resonance imaging (fMRI), and (b) studies of the temporal dynamics of fast activity changes in the brain, as revealed by high-frequency responses recorded in the electroencephalogram (EEG) and magnetoencephalogram (MEG). These data provide evidence for processing differences between words and matched meaningless pseudowords, and between word classes, such as concrete content and abstract function words, and words evoking visual or motor associations. There is evidence for early word class-specific spreading of neuronal activity and for equally specific high-frequency responses occurring later. These results support a neurobiological model of language in the Hebbian tradition. Competing large-scale neuronal theories of language are discussed in light of the data summarized. Neurobiological perspectives on the problem of serial order of words in syntactic strings are considered in closing.

Perceptual fluency and lexical access for function versus content words

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Abstract: By examining single-word reading times (in full sentences read for meaning), we show that (1) function words are accessed faster than content words, independent of perceptual characteristics; (2) previous failures to show this involved problems of frequency range and task used; and (3) these differences in lexical access are related to perceptual fluency. We relate these findings to issues in the literature on event-related potentials (ERPs) and neurolinguistics.

Pulvermüller (1999) posits that lexical access for function words involves the perisylvian region whereas lexical access for content words additionally involves other cortical areas related to the specific meanings. Function word cell assemblies should produce faster lexical access times, because they are more concise in the geographical sense and possibly because functions whose representations are restricted to this area are deemed to be more automatized (Whitaker 1983). However, the experimental literature on function word and content word lexical access times does not support this. Pulvermüller et al.'s (1995) own data show that lexical decisions are slower for function words than for content words. We (and many others) have found this too: lexical decisions for function words took more that 40 msec longer than for nouns and verbs (which did not differ from each other), $F(2, 34) = 21.9, p < .001$ (Segalowitz & Chevalier, unpublished data).

Some researchers have suggested that the lexical decision paradigm is not an appropriate one for comparing function and content words on access times. Taft (1990) showed that lexical decisions are slower for words that do not comfortably stand alone, whether of the function type or the content type, and Schmauder (1996) found that function words and content words show the same lexical decision times when they are embedded in sentences that are read for meaning. Some support for a faster access time for function words is presented in Neville et al.'s (1992) ERP finding of a distinctive negative component at 280 msec for function words and at 350 msec for content words. The result was not found to be due to word frequency (although there were range restrictions) or word length; however, repetition within the paradigm, and word predictability, were not explored. (The original object of the study was to examine variations in the congruity of the last word with respect to sentence meaningfulness.) In order to examine lexical access of words read for meaning while controlling word characteristics, we presented sentences from Neville et al. (1992) and Schmauder (1996) one word at a time (500 msec duration, 1200 msec SOA) to subjects who read them aloud for sentence meaning. We then scored the reading times for each word, not including the first and the last word of each sentence or the few words where subjects' articulation did not distinguish adjacent words (Segalowitz & Lane 2000).

We obtained similar results whether we analyzed frequency (high, medium, low) by word type in a standard ANOVA procedure (see Table 1), or whether we treated words as cases in a regression by standardizing each subject's reading times (RTs) and averaging across subjects: We found unique variance contributions to RT from length (shorter words were faster), $t = 3.1$, $p < .005$; frequency (higher frequency words were faster), $t = 3.1$, $p < .005$; and word type (function words were faster by 23 ms), $t = 2.3$, $p < .025$, in addition to the common variance. This shows for the first time that functions words are indeed accessed faster than are content words in meaningful contexts independent of these other characteristics. As expected, function words are of higher word frequency and shorter length on average. They also repeated more of-

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Table 1. *Average reading times (msec) for function words and content words at different levels of word frequency. Word frequency criteria are indicated as occurrences out of a million (Kucera & Francis 1967).*

	SuperHigh >10000	High 883–10000	Medium 125–877	Low 0–122
Content Words	—	454	470	488
Function Words	457	453	455	506
Average reading times for first occurrences only				
Content Words	—	454	473	492
Function Words	446	448	460	506

ten within the 188 sentences, but when we partialled out word repetition as well as word length, we obtained the same results.

In addition, we found the Word Type *x* Frequency interaction to be significant ($F(1, 1526) = 21.2, p < .0001$), indicating that the frequency effect (high frequency words being accessed more quickly than low frequency words) is different across word types. Since many words (especially function words) are repeated, we also examined only the first presentations and obtained the same results. However, as Gordon and Caramazza (1982) pointed out, the interaction is strongly related to the confound of word type with frequency, for although content words show a near-linear frequency effect as expected, function words show an increase in RT only at the lowest frequencies. Therefore, depending on the frequency range of function words used, the disparity between word types in frequency effect can be manipulated – any range with a bottom frequency cutoff up to 310/million produced a significant word type by frequency interaction.

Ours are the first fully supportive behavioral data we know of for the privileged access and this was found using meaningful sentence contexts. This is consistent with Pulvermüller's (1999) data which suggest a more concise storage pattern for function words, and Neville et al.'s (1992) finding of an earlier ERP component for function words. However, meaningful sentence contexts confound many factors. Function words may show a special link with the left anterior region because they are accessed more automatically on account of higher perpetual fluency, more experience reading them (higher word frequency in the language), shorter length, or even greater repetition within the study. We found that reading time differences between word types were not related to word length or repetition. But this link could also be to the result of greater predictability of the common function of words. To test this last possibility we gathered from a new set of subjects Cloze judgments (ability to predict the word from the sentence context leading up to it) of one word from each sentence. As expected, high-frequency function words were clearly more predictable (see Table 2), as were function words, which were concentrated in the highest frequency range.

Table 2. *Predictabililty values (percentage of subjects correctly guessing the stimulus word from its preceding sentence) for function and content words at different levels of word frequency gathered in Cloze procedure. Frequency values are out of 1,000,000 printed words (Kucera & Francis 1967).*

	SuperHigh >10000	High 883–10000	Medium 125–877	Low 0–122
Content Words	—	17.3	15.5	10.1
Function Words	45.6	25.1	9.3	2.0

Of particular interest is the finding that predictability (Cloze values) and word frequency (log frequency occurrence in the language) each account for the significant variance in reading times ($p < .0001$), and after this variance is removed, neither word type nor the frequency by word type interaction is significant. In other words, from our data we would conclude that the difference in reading times between word classes is due to factors relating to perceptual fluency. By extension, the electrocortical effects of word class are a reflection of these characteristics, especially in natural contexts of reading sentences for meaning. However, in the real world, this is where words occur, and function words indeed occur with greater frequency and are more predictable. Thus, the brain mechanisms responding to lexical access in meaningful contexts should differentiate function and content words because processing them lexically involves different levels of perceptual fluency.

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Authors' Response

Determinants of ignition times: Topographies of cell assemblies and the activation delays they imply

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Abstract: The cell assembly model of language posits that words are laid down in the cortex by discrete sets of neurons distributed over specific parts of the brain. The strong internal links of these "word webs" may not only bind articulatory and acoustic knowledge of a lexical item, they may also link word and meaning; for example, by connecting neuron populations related to word forms to those of actions and perceptions to which the words refer. Therefore, the cortical activation elicited by words should reflect aspects of word meaning, a postulate that has received strong support from recent work using neurophysiological and metabolic imaging. **Segalowitz & Lane** make the point that this neurobiological model can also be used to predict reaction times in behavioral experiments, using the behavioral distinction between content and function words as an example. We acclaim their view, but warn that response times might be related to different mechanisms at the neuronal level, including the cortical distribution and internal connectivity of cell assemblies along with their mutual connections in the grammatical (syntactic and semantic) network.

R1. Cell assemblies with distinct topographies binding words and their meaning

Laws governing neuronal function, such as the correlation learning principle, and the knowledge about cortical connectivity can be used to predict cortical circuits involved in language processing (Pulvermüller 1999; 2002). This approach is explanatory because it deduces the where and when of cortical processing from biological principles. It predicts that acoustic word form knowledge and articulatory word form knowledge are bound together by

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