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ASSOCIATIVE ACQUISITION OF WORD MEANING BY TRIAL-AND-ERROR LEARNING[1]

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Word-specific memory traces in the brain are supposed to be formed in the process of mutual connection strengthening between different brain areas; this happens as actions, objects or concepts are learnt when they are experienced in conjunction with the words used to describe them (Pulvermuller, 2005). The ability to quickly acquire word-picture associations was shown to depend on the reorganization in neocortical networks including the left temporal area, especially the left temporal pole (Sharon et al., 2011), as well as temporoparietal, premotor, and prefrontal regions (Majerus et al., 2005; Mestres-Misse et al., 2008; Paulesu et al., 2009; Sharon et al., 2011). Yet, very little is known about the localization of the earliest stages of this process.

We designed a behavioral paradigm that involves rapid word meaning acquisition. This procedure mimics important aspects of natural word learning and is most relevant to associative biological interpretation of word meaning acquisition. We attempted to find time and location of significant events in the brain linked to acquisition of word meaning.

Twenty-eight adult Russian-speaking right-handed participants took part in the experiment. Participants were presented binaurally with eight two-syllable pseudowords; four of them (referred below as «words») were assigned to specific body part movements during the course of learning – through commencing actions by any of participant's left or right extremities and receiving an auditory feedback. The other pseudowords – referred below as «distractors» – did not require actions, and were used as controls to account for repetition suppression, which is typically observed when spoken words or pseudowords are presented repeatedly (Majerus et al., 2005; Paulesu et al., 2009).

Magnetoencephalogram was recorded using "VectorView" (Elekta Oy, Finland), before and after learning. Statistical significance of the root mean square (RMS) response over sensors was assessed for the double difference:

$(W1- D1) - (W2 - D2)$,

whereW1 and W2 stand for magnetic evoked responses to «words», and D1 and D2 – for magnetic evoked responses to «distractors» before and after learning correspondingly. We used t-tests with max-cluster-size permutation

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procedure to account for multiple comparisons. The cortical sources of the magnetic evoked responses were reconstructed using distributed source modeling (minimum-norm estimation). Cortical areas were obtained as clusters of significant voxels ($p<0.05$) within specific time windows revealed by the RMS analysis.

Analysis of the RMS signal produced two statistically significant intervals: 230-280 ms and 465-515 ms after the disambiguation point in the left hemisphere. For the time interval 230-280 ms, the effect was found in two clusters of voxels, both in the left hemisphere, in perisylvian cortical regions (figure 1). One was located in the middle part of the superior temporal sulcus (STS), extending dorsally into the superior temporal gyrus (STG), – mostly auditory parabelt areas. The other one included the frontal operculum and the insula. Importantly, the effect of word meaning acquisition was evident only in the left hemisphere.

Learning-related cortical activation in the temporal cluster was inversely related to the number of trials needed to acquire the word meaning ($p= 0.04$). This proves that the effect observed is indeed relevant to formation of a memory trace linking the acoustic pattern of the pseudowords to their meaning (i.e. actions).

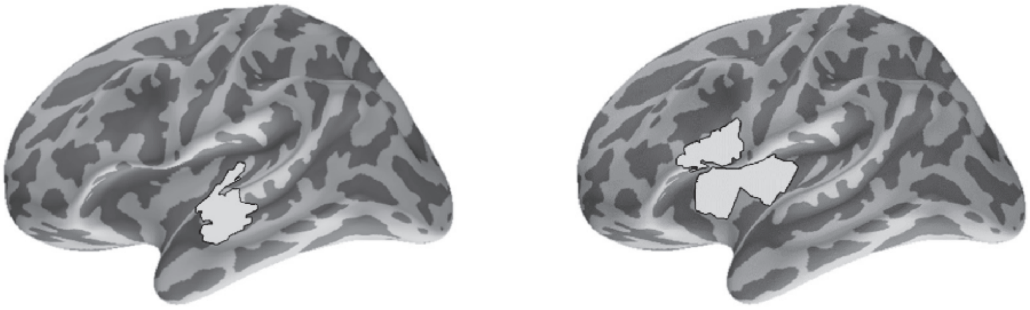

Figure 1. **Significant spatial clusters on the left cortical surface: middle STS/STG (left panel), frontal operculum and insula (right panel)**

In contrast to the current body of literature (Majerus et al., 2005; Mestres-Misse et al., 2008; Paulesu et al., 2009; Sharon et al., 2011), we found a significant effect in the middle part of the STS/STG that mostly included the auditory parabelt areas responsible for spectrotemporal analysis (Hickok and Poeppel, 2007) and initial steps of word recognition (Scott and Johnsrude, 2003; Scott and Wise, 2004). Processing of a new word also activated the posterior opercular part of the inferior frontal gyrus that is involved in subvocal rehearsal and articulatory coding of the perceived speech sounds (Hickok and Poeppel, 2007), this fact emphasizing the role of articulatory sensory-motor experience in acquisition of word meaning.

Our findings imply that long-term effects of natural language usage may involve multiple consolidation/reconsolidation phases, and rooting the word meaning into one's sensory-motor experience is a necessary but not a sufficient prerequisite for its embedding into the associative structure of semantic memory.

Taken together, our findings show that learning of novel word meaning through word-action association selectively increased neural specificity for these words in the auditory parabelt areas responsible for spectrotemporal analysis, as well as in articulatory areas, located in the left hemisphere. Importantly, this effect was detected in passive conditions after active learning, evidencing formation of a robust memory trace. The extent of neural changes was linked to the degree of language learning, specifically implicating the physiological contribution of the left perisylvian cortex in the learning success.

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