Neurocognition of New Word Learning in the Native Tongue: Lessons From the Ancient Farming Equipment Paradigm

Matti Laine
˚Abo Akademi University

Riitta Salmelin
Aalto University School of Science and Technology

Here we review behavioral, neuroimaging, and neuropharmacological studies using a word learning task labeled as the Ancient Farming Equipment paradigm. This task has been used to explore the neural correlates of explicit learning and maintenance of new names for novel objects in the native tongue. The main conclusions drawn from these studies are as follows: (a) Retrieval of both the newly learned and familiar names is subserved by predominantly left hemispheric cortical regions; (b) within this network, retrieval of newly learned words can be accomplished in different ways depending on the exact form of training; (c) patient studies indicate that episodic memory mechanisms subserved by hippocampal structures are related to word acquisition rather than to long-term maintenance of newly learned words; (d) explicit learning and maintenance of novel words can be facilitated by neuropharmacological manipulation that boosts the dopaminergic system; and (b) neural events following completed training may predict long-term retention of newly learned words.

Languages are not static: They are in a slow but constant flux where, for instance, new words, expressions, and shades of meaning appear and others may...

The authors were supported by the Academy of Finland (Centre of Excellence Programme 2006–2011, Neuro2005 Programme, research grant #129160), the Finnish Cultural Foundation, the Sigrid Junélius Foundation, and a NOS-HS grant for the Nordic Centre of Excellence in Cognitive Control. We wish to thank Annika Hultén for help with the figures. She and Antoni Rodríguez-Fornells also gave valuable comments on an earlier version of this article.

Correspondence concerning this article should be addressed to Matti Laine, Department of Psychology, Åbo Akademi University, Fabriks gatan 2, FI-20500 Turku, Finland. Internet: matti.laine@abo.fi; or Riitta Salmelin, Low Temperature Laboratory, Aalto University School of Science and Technology, P.O. Box 15100, FI-00076 Aalto, Finland. Internet: riitta@neuro.hut.fi
gradually fall out of use. An individual entering a new field, be it for a profession or for a hobby, is also typically faced with a new vocabulary that has to be learned. Thus, not only second language learners but even monolingual language users must constantly update and maintain their language representations, particularly the mental lexicon where the changes are most prominent. This calls for mechanisms for learning and maintenance of new vocabulary that is in use throughout the life span.

Word acquisition apparently entails several aspects of memory and learning, extending from the ability to recognize newly learned items to the active use of the new word in relevant linguistic and pragmatic contexts. In general terms, the large scope of word acquisition finds a correspondence in biological models of memory that differentiate between hippocampal and neocortical contributions to memory. The former system specializes in building fast and automatic arbitrary associations between representations, whereas the latter gradually integrates new information with existing knowledge (O’Reilly & Norman, 2002). One would thus expect that for the initial encoding of novel words and their referents, the hippocampal systems are crucial, whereas the integration of the new word into the mental lexicon calls for the neocortical systems. Indeed, studies that have looked at the neural underpinnings of word learning with different paradigms have identified a number of brain areas, including both hippocampal regions (Breitenstein et al., 2005) and several neocortical areas, especially the left temporal lobe (Raboyeau et al., 2004), left inferior parietal lobe (Breitenstein et al., 2005), and left inferior frontal region (James & Gauthier, 2004). Reliance on the “language cortex” is evident in these studies, as the cortical activations related to vocabulary acquisition are typically left-sided.

In the present article, we will review and discuss neurocognitive studies that have employed a specific word learning task, labeled here as the Ancient Farming Equipment (AFE) paradigm. This paradigm taps explicit, gradual acquisition of new active vocabulary. AFE studies have not addressed the initial encoding of the novel items, and one would thus expect to find neocortical correlates of word learning with this paradigm, following the general framework of complementary hippocampal versus neocortical learning systems in the brain briefly described earlier.

The Ancient Farming Equipment Paradigm

The AFE paradigm was designed to study the acquisition of new words in the native tongue. Similar to real-life learning of new concrete nouns, it requires the
acquisition of a previously unknown object, a novel name, and an association between the two. When seeking for a suitable set of real but unfamiliar items, the first author came across an old Finnish ethnological dictionary with black-and-white object drawings and descriptions of ancient artifacts previously used in Finnish households. With this rich source of items, we formed stimulus sets to study the neurocognitive correlates of the acquisition of new names versus meanings (object definitions) in the mental lexicon. We focused on the acquisition of active vocabulary for which learning success was measured by oral naming of the novel objects. This entails that the participants had to establish a link between the visual representation of the object and the corresponding phonological output form. Whereas naming of familiar objects typically requires that the meaning of the object is also retrieved (e.g., Laine & Martin, 2006), it must be possible to name newly learned objects by direct visual-phonological links, too. We will return to this issue later.

For the training, we employed a computerized setup in which the participant was repeatedly exposed to the novel items (Figure 1). Depending on the stimulus category, the item included an object image coupled with its written name (e.g., “NAHTURI”; Name condition), written definition (e.g., “a carrying net made of cord”; Def condition), or both (NameDef condition). The aim of this manipulation was to study the effects of semantics on word learning: The definition might lead to a “deeper” processing of that item than the mere provision of a new name for an unknown object. For control purposes, we had an additional category of unfamiliar, novel objects for which no phonological or semantic information was provided (UnFam), as well as a set of similar black-and-white drawings of familiar objects (Fam). Learning was tested by picture naming in which the participant’s task was to produce the name for the objects to which a name had been provided (the Name and the NameDef categories; otherwise, the generic name “object”). To enable comparable learning outcomes for the participants, we employed a training to criterion setup.

In Search of the “Word Learning Device”: The First Neuroimaging Study Using the AFE Paradigm

Prelude: Training-Related Changes in Naming in Aphasic Patients
The first functional neuroimaging study with the AFE paradigm was inspired by our previous experiment on the cortical correlates of relearning of words in aphasic patients (Cornelissen et al., 2003). In that study, three chronic aphasic patients with moderate anomia underwent an intensive 3-week treatment period on sets of familiar objects that they could no longer name. Even though the
patients exhibited different clinical aphasia profiles (two fluent, one nonfluent), more detailed testing revealed that they all suffered from predominantly post-semantic anoma. In other words, they could access the meaning of the target items but had problems retrieving the corresponding phonological output form. The theory-driven treatment program employed with the patients, labeled as the contextual priming technique, combines intensive repetition of the target names together with semantic priming (several semantically related items trained at the same time), aiming to boost the lexical-semantic representations of the targets and strengthen the disordered links between the lexical-semantic and lexical-phonological representations (see, e.g., Laine & Martin, 1996; Martin & Laine, 2000).
To detect possible training-related changes in cortical activity during naming, the patients underwent a total of four testing sessions with magnetoencephalography (MEG). We performed two measurements prior to the training period and two after the training in order to be able to draw reliable conclusions on training effects in a damaged brain that typically exhibits increased stimulus-nonrelated neural activity (“noise”). MEG taps the very weak magnetic field of synchronized postsynaptic potentials in neuronal populations, mainly in cortical areas. It provides an excellent temporal resolution that is important as neurocognitive processes unfold at the millisecond level. In addition, MEG provides a good spatial resolution of the cortical sources through advanced signal processing techniques.

Behavioral results indicated that the fluent patients exhibited good treatment effects on the trained items, whereas for the single nonfluent patient, treatment success was only moderate. In the MEG, the possible neural correlates of treatment facilitation were sought by comparing pretreatment versus posttreatment brain responses to trained versus untrained items in a delayed naming task (a delay between the picture presentation and the naming response was used to avoid movement artifacts that would disturb MEG data analysis). Interestingly, in all three patients with somewhat different lesion loci and aphasia profiles (but a functionally more or less similar anomic deficit), a single source area, located in the left inferior parietal lobe close to the lesioned areas, showed significant treatment-related changes when the participants named the trained items. In the fluent patients, the amplitude of this brain response increased significantly after successful training, whereas in the nonfluent patient, who showed only temporary and moderate facilitation of target naming, a significant decrease in amplitude was noted. Further analyses indicated that these changes did not merely reflect an increase in the number of correctly named target pictures. Timewise, the observed effect was quite late, as it started approximately 300–600 ms after picture presentation. Given the late time window, the type of anomic deficit in the patients and the treatment method used, Cornelissen et al. (2003) interpreted the neural effect as reflecting treatment-related changes in phonological output processing (see also Indefrey & Levelt, 2004). The surprisingly uniform pattern of findings in the three patients was tentatively related to verbal working memory that has been strongly implicated in new word learning (for a review, see Baddeley, Gathercole, & Papagno, 1998). Verbal working memory tasks activate frontoparietal systems, and within this network, the rehearsal component has been related to premotor cortex and Broca’s area function and the phonological storage component has been linked to left parietal activity (e.g., Awh et al., 1996; Jonides et al., 1998). In other words,
the altered retrieval-related left parietal activity in the patients may have reflected more effective retrieval processes in the phonological output lexicon as a result of reestablished semantic-to-phonological links for the target representations. The observation of a uniform treatment-sensitive region in the vicinity of the patients’ brain lesions suggests that this area was a particularly important component in phonological output and learning and could not be replaced, for instance, by the right hemisphere structures that had remained intact in the patients.

**New Word Learning in Normals as Measured by MEG**

If the clinical evidence by Cornelissen et al. (2003) reviewed earlier indeed reflected the reactivation of a central component in a “word learning device,” a similar result should be obtained when normals retrieve newly learned words. Accordingly, we constructed the AFE paradigm to test this hypothesis in a subsequent study (Cornelissen et al., 2004).

In this study, five right-handed young normal adults were trained on pictures of unfamiliar old artifacts. In order to examine the possible role of semantics on learning to name and to provide the necessary control conditions, we employed a total of five different item sets (see Figure 1): NameDef, Def, Name, UnFam, and Fam. The participants were instructed to read the name and/or the definition if that was provided with the picture, but the task was to learn the names. The learning phase consisted of self-training on a computer where the participants were exposed to the training material and then performed a paper-and-pencil naming task to document their progress in learning. They trained every weekday until the preset criterion level (at least 98% of the NameDef and Name items named correctly) was reached.

The MEG measurement was performed at three time points. The first session was conducted before the start of the training, the second at the point when at least 50% of the target names were produced correctly, and the third when the criterion level (98% or more correct naming responses) was reached. In the MEG sessions, the delayed naming paradigm was used (for the items that could not be named, the participant was instructed to provide the generic name “object”). The items were presented in random order.

The behavioral results showed that all subjects except one needed to complete only four to five training sessions in order to reach the criterion level on object naming. Overall, the naming-related cortical responses as measured by MEG showed the previously reported activity pattern over different subjects and test sessions: Activations proceeded from the occipital, temporal, and parietal areas to the motor regions (Levelt, Praamstra, Meyer, Helenius, & Salmelin,
In the pretraining measurement, all novel items (NameDef, Def, Name, and UnFam) elicited similar cortical responses that were weaker than to the Fam items in the 400–800-ms time window. Of particular interest were the training-related effects that were clearest when the criterion level of 98% correct responses was reached (see Figure 2). For all five subjects, there were one to two long-latency (400–750 ms after picture exposure) sources that differentiated the new items for which the name was provided (NameDef, Name) from the other novel objects (Def, UnFam). In three subjects, we found a training-sensitive source in the left inferior parietal lobe. In two subjects, a right hemisphere training-sensitive source was located: for one subject in the inferior parietal lobe and for the other in the inferior frontal cortex. Cornelissen et al. (2004) concluded that these results are quite well in line with their earlier evidence obtained from the relearning experiment with aphasics, thus supporting the hypothesis that the inferior parietal lobe plays an important role in word acquisition due to its role in the working memory system. More specifically, the observed inferior parietal activity could reflect a phonological storage function (Baddeley et al., 1998) or attentional scanning used to reactivate verbally coded information (Chein, Ravizza, & Fiez, 2003). In turn, the observed variability in the location of the training-sensitive source areas (right-sided in two subjects) might reflect alternative ways of accomplishing the associative learning task—for instance, via a stronger reliance on visual working memory (see Duyck, Szmalec, Kemps, & Vandierendonck, 2003). The provision of semantic information during training did not affect subsequent naming-related brain responses: One reason may be that the definitions were not directly relevant to the task at hand (learning of the object names).

Left Hemisphere Structures Supporting Newly Learned Words: Evidence From Subsequent Neuroimaging Studies Using the AFE Paradigm

The AFE paradigm was also employed by Grönholm, Rinne, Vorobyev, and Laine (2005). This study provides some testing ground for the generalizability of the findings reviewed earlier, as Grönholm et al. had elderly normals as their subjects and measured naming-related regional brain activity by a regional cerebral blood flow (rCBF) measure—namely, positron emission tomography (PET) with the short-lived isotope of oxygen (oxygen-15) as the radioactive tracer. Certain aspects of the study design deviated from the one used in the MEG study by Cornelissen et al. (2004). There were only 20 objects per...
Figure 2  Cortical areas showing significant (**p < .01) learning-related effects in five subjects at the end of the training when the criterion level (98% correct in naming the NameDef and Name objects) had been reached. The active cortical patches are modeled as pointlike centers of activity (equivalent current dipoles). Figure from Cornelissen et al. (2004) by permission of the publisher.
category (NameDef, Name, UnFam, Fam), the Def category was left out, a fixed number of daily training sessions (four) was used, the subjects were instructed to read the names and the definitions aloud during training (the experimenter was present throughout the training), the PET measurement was performed posttraining only, item categories were blocked in PET (trial-by-trial analyses are not possible), and during PET scanning the subjects were instructed to name the objects immediately after presentation rather than after a delay.

Ten right-handed healthy elderly participants (mean age: 65.5 years; range: 56–77 years) served as subjects. All subjects learned to name the NameDef and Name items well, with a mean percentage of 94% correct responses after the four training sessions. Over the four training sessions, the acquisition of the Name category names was better than the acquisition of the NameDef object names. One possible reason may be the nature of the task: The subject was instructed to learn the name, and the definition providing additional information might even have been somewhat distracting. Interviews with the subjects after the training indicated that both for the NameDef and the Name items, self-generated semantic and phonological cues were commonly used as retrieval aids. As the PET contrasts between the brain responses to the NameDef and the Name items were nonsignificant, these items were pooled together to form a category of Trained items. The Trained items were then contrasted separately to the Fam and the UnFam items. The former contrast revealed rCBF increases in the left inferior frontal region (Broca’s area), the left anterior temporal area, and the cerebellum. For the latter contrast, more extensive left frontal (in and around Broca’s area) and cerebellar rCBF increases were noted, together with bilateral anterior temporal activation increases (Figure 3).

The PET results indicated a strong response in left inferior frontal and anterior temporal regions as well as the cerebellum during retrieval of newly learned names. Grönholm et al. (2005) noted that the left inferior frontal activity may be linked to phonological and/or semantic retrieval processes, whereas the left anterior temporal activity that is less commonly observed in familiar object naming might reflect the engagement of an interface region that mediates semantic memory retrieval from more posterior temporal regions, as suggested by Markowitsch (1995). Surprisingly, the training-related left inferior parietal lobe activity that was the most prominent finding in the AFE study with MEG did not come up in the PET analyses. It is hard to pinpoint the reason for this discrepancy, as the setup for the PET experiment was different from the MEG study in several ways, as noted earlier. Moreover, the physiological measures are, of course, different, as MEG taps synchronized neural activity and PET with the oxygen-15 radiotracer reflects local blood flow in the neural tissue.
A very recent MEG study with the AFE paradigm (Hultén, Vihla, Laine, & Salmelin, 2009) provides some clues to this discrepancy in the neural substrates of the retrieval of newly learned words. The stimulus categories and training setup were the same as in Cornelissen et al. (2004). However, there were some differences as well: In the new study, the subjects were instructed to learn not only the names but also the definitions of the novel objects, MEG measurements related to word learning were extended from picture naming to phonological and semantic categorization tasks, and the subject group was twice as large (i.e., 10 subjects) as in the Cornelissen et al. experiment.

It took three to six daily computerized training sessions for the 10 subjects to reach the preset criterion level of 98% correct object naming responses. In this group, acquisition of the object names was not affected by the presence (NamDef items) or absence (Name items) of a definition. Additional testing indicated that the participants were also very efficient in acquiring the object definitions (the NameDef and Def items). Analysis of the MEG data indicated that the subjects’ naming-related sources were clustered in six cortical regions: occipital, left and right parietal, left temporal, and left and right frontal. Similarly to the earlier MEG studies on picture naming (Cornelissen et al., 2004; Levelt et al., 1998; Salmelin et al., 1994; Vihla, Laine, & Salmelin, 2006), the overall results showed a wave of cortical activation proceeding through the regions of interest from bilateral occipital cortex (<200 ms after picture onset) through parietal (200–400 ms) to left temporal and bilateral frontal cortex (>300 ms). With regard to training effects in naming, long-latency cortical
responses to the Name and NameDef items increased significantly in the left posterior temporal cortex and in the bilateral posterior frontal cortex (see Figure 4). The parietal source clusters did not exhibit training-related activity changes. Phonological and semantic categorization tasks with the newly learned objects exhibited source distributions largely similar but not fully identical with that of picture naming (see Hultén, Vihla, et al., 2009, for the results).

The naming-related training effects reported in the Hultén, Vihla, et al. (2009) study show more overlap with the Grönholm et al. (2005) than the Cornelissen et al. (2004) results, although the left temporal findings were disparate (anterior-superior regions in Grönholm et al.; posterior inferior-to-superior regions in Hultén, Vihla, et al.). Thus, Hultén, Vihla, et al. failed to replicate the findings of training-sensitive left inferior parietal sources during retrieval of object names reported by Cornelissen et al. (2003, 2004). The discrepancy cannot be due to the functional imaging method used, as both Hultén, Vihla, et al. and Cornelissen et al. (2004) employed MEG. Even many aspects of the experimental design, including the use of a delayed naming task, were similar. However, there was an important difference in the task: Hultén, Vihla, et al. instructed their participants to learn both the names and the definitions. Accordingly, Hultén, Vihla, et al. suggested that their participants learned to access the new phonological forms via verbal semantics (thus the left-lateralized training effects in the frontotemporal areas), not through direct visual-phonological associations that might have been the case in the study by Cornelissen et al. (2004) (thus strong engagement of the phonological loop and the training-related modulation of left inferior parietal cortex activation). One would need to postulate a similar semantically driven word learning strategy for the elderly subjects of the Grönholm et al. (2005) study as well, although, similarly to Cornelissen et al. (2004), these subjects were not instructed to learn the definitions. Interestingly, the elderly participants did report a regular use of self-initiated semantic and phonological cues in the learning task. The limited number of items the elderly subjects were exposed to might have encouraged the use of semantic/phonological associations in word learning. There is also evidence from word list learning that the use of semantic associations is more pervasive in older than in younger adults (Golomb, Peelle, Addis, Kahana, & Wingfield, 2008).

**Memory Impairment and Word Learning**

Grönholm-Nyman and her colleagues extended the use of the AFE paradigm to clinical populations by testing the word learning ability of patients with mild
Figure 4  Group-level results in object naming pretraining and posttraining.  **Left:** Clustering of sources in six cortical regions of interest. Each dot represents the center of an active cortical patch in one individual. For each cluster, the number of participants with a source in that area is given in parentheses (one source per region per participant both in the figure and in the analysis).  **Middle:** Grand average time courses of activation in the depicted source clusters before and after training. The different stimulus categories are depicted by different line types.  **Right:** Peak amplitudes (mean + standard error of
cognitive impairment (MCI) and mild Alzheimer’s disease (AD) (Grönholm-Nyman, Rinne, & Laine, 2010). In addition to its clinical interest concerning the learning potential of a damaged brain, this study gives the possibility to explore especially the role of episodic memory in learning to name novel objects. Previous studies on acquisition of new vocabulary in densely amnesic patients have provided equivocal results, indicating either no (e.g., Verfaellie, Croce, & Milberg, 1995) or limited (e.g., Kitchener, Hodges, & McCarthy, 1998) vocabulary acquisition after a sustained medial temporal lesion and subsequent severe episodic memory impairment.

The MCI patients \( (n = 13) \) of Grönholm-Nyman and her colleagues suffered from the so-called amnesic MCI, that is, their primary cognitive defect was an episodic memory impairment. The mild probable AD patients \( (n = 9) \) tested in this study, in turn, suffered from both a severe episodic memory impairment and a semantic memory impairment as verified by a neuropsychological test battery. Twelve healthy elderly subjects served as controls. Previous structural and functional brain imaging evidence has indicated that a dysfunction of the hippocampal/medial temporal memory system underlies the episodic memory impairment in amnesic MCI and AD, whereas the emerging semantic memory impairment in AD is related to progressive posterior cortical dysfunction (see, e.g., Grönholm-Nyman, 2009).

The behavioral part of the study was the same as in the Grönholm et al. (2005) PET study described earlier, except for a 2-month posttraining follow-up. The follow-up test sessions also included additional tests that tapped object recognition memory, incidental learning and maintenance of the object definitions, and sensitivity to phonological cueing in naming.

Acquisition of object names was significantly impaired in the MCI and AD patients, but forgetting rates for the names that the participants had acquired did not differ among the three groups. This suggests a considerable episodic memory component in learning active new vocabulary, whereas the maintenance of already acquired names relies on other, presumably neocortically based memory systems. Interestingly, at the final follow-up session, 2 months posttraining,
the MCI patients showed better name recall for the items for which a definition had been provided during training (the NameDef items) than for the items for which only a name had been given (the Name items). Grönholt-Nyman et al. (2010) interpreted this as a compensatory effect where MCI patients rely on their well-preserved semantic memory. The accompanying definitions may thus have been more important for the MCI patients than for the controls. Note that the MCI patients also reported much less self-initiated semantic and/or phonological retrieval strategies.

Object recognition memory and incidental learning of the definitions was impaired in the AD patients but not in the MCI group, supporting the view that these types of memories are mediated by other memory systems than the hippocampal one that was presumably affected in the MCI group. Finally, both patient groups showed relatively less facilitation from phonological cueing in picture naming, suggesting that their word retrieval problems were not at the “tip-of-the-tongue” stage, but deeper.

In order to shed light on possible brain activation differences between MCI patients and controls during name recall for newly learned words, Grönholt, Rinne, Vorobyev, and Laine (2007) ran the PET activation experiment reviewed earlier with 10 right-handed MCI patients. Although the MCI patients’ name acquisition was significantly worse, the only difference in the naming-related activation patterns between the patients and the controls was in the anterior cingulate, where activity levels were significantly higher in the patients naming the Name items. This presumably reflects higher executive and attentional demands posed by the task in the MCI group that exhibited impaired word learning (see, e.g., Bush, Luu, & Posner, 2000).

Neuropharmacological Aspects of Novel Word Learning

Memory and learning can be boosted or inhibited by a number of pharmacological agents, and psychopharmacological studies provide important clues to the neurotransmission underlying these processes. One such agent is dextroamphetamine (AMPH) that has been shown to augment language and motor recovery in stroke when coupled with behavioral treatments (Martinson & Eksborg, 2004). In normals, AMPH induces cognitive and physiological changes and it has, among other things, been shown to enhance word list learning (Soetens, Casaer, D’Hooge, & Hueting, 1995) and associative word learning (Breitenstein et al., 2004). AMPH increases the concentration of catecholamines in the synaptic cleft and its cognitive effects are assumed to be mediated mainly via dopaminergic changes. The dopaminergic system is assumed to play
a coordinating role in cognitive function, probably through working memory and attentional effects mediated by prefrontal regions that are innervated by ascending dopaminergic pathways (Nieoullon, 2002).

Recently, Whiting, Chenery, Chalk, Darnell, and Copland (2007) conducted a pharmacological intervention study on explicit word learning by using the AFE paradigm. The young healthy participants \( n = 37 \) in this between-group placebo-controlled double-blind study were administered AMPH (10 mg per learning session) or placebo prior to word learning sessions over five consecutive mornings. The participants had to learn the pseudoword names and/or fictive definitions of 100 unfamiliar artifacts (Name, NameDef). Learning and maintenance was tapped by name retrieval and name recognition during the five learning sessions, as well as 1 week and 1 month after the training sessions.

As compared to the placebo group, the AMPH group was significantly better in both name retrieval and recognition during both the learning sessions and the two follow-up tests. The two study groups did not differ on measures of cardiovascular arousal (the AMPH dose was quite small) and mood ratings indicated higher tenseness in the AMPH group that nevertheless did not correlate with learning performance. Whiting et al. (2007) concluded that AMPH can indeed facilitate novel word learning, possibly by boosting dopaminergic mechanisms of working memory and/or by enhancing memory consolidation.

**Neural Predictors of Long-Term Success in Word Acquisition**

An essential aspect of new word learning is the ability to effectively maintain the recently acquired words over longer periods of time even if they are not regularly used. By analyzing follow-up data from the participants in the Hultén, Vihla, et al. (2009) study, we recently explored the long-term maintenance of word learning (Hultén, Laaksonen, et al., 2009).

The follow-up period after successful word learning spanned over almost a year, with behavioral tests and naming-related MEG measurements 1 week, 4 weeks, 8 weeks, and 10 months after training. Although the learning curves of the 10 normal participants were fairly similar and all reached the criterion level of 98% correctly named items, there was considerable interindividual variation at 10 months posttraining, as the participants’ name recall varied between 20% and 88%. This prompted us to search for possible neural precursors in the MEG data that could predict the long-term outcome in name recall. Interestingly, individual changes of activation strength in left frontal and temporal naming-related sources 1 week after successful learning correlated with the participants’ performance at the end of the follow-up period. More
specifically, an increase in activation strength in these sources within 1 week of learning was related to a high performance 10 months later, whereas decreased activation strengths were linked with poorer name retrieval at the end of the follow-up.

Although the present data are intriguing, they need to be replicated in further studies. Additionally, the underlying neural mechanisms remain open. One possibility is that these changes following learning reflect memory reconsolidation processes, where each time a word is recalled the underlying memory trace may be either strengthened or weakened depending on the characteristics of the recall episode.

Conclusions

The present review has focused on results obtained from a specific type of word acquisition paradigm that taps the explicit learning of novel concrete entities and their names in the native language. Rather than examining immediate learning effects, the AFE paradigm has been used to address the gradual acquisition of active vocabulary over several days and the long-term outcome of this learning process. The main emphasis in these studies has been on the neural correlates of word learning and maintenance, mainly measured by picture naming. Based on the studies reviewed earlier, we draw the following five general conclusions:

1. **Retrieval of both the newly learned and familiar names is subserved by predominantly left hemispheric cortical regions.** In the context of the general framework of the neurobiology of memory (O’Reilly & Norman, 2002), the AFE paradigm is expected to engage neocortical learning mechanisms that integrate new information with existing knowledge in a gradual fashion. Indeed, both the neurophysiological (MEG) and hemodynamic (PET) evidence reviewed earlier indicates that retrieval of newly learned words activates predominantly left hemispheric cortical regions (Cornelissen et al., 2004; Grönholm et al., 2005; Hultén, Vihla, et al., 2009). The MEG results indicated that retrieval of both newly learned and already familiar words activate the same cortical networks. The PET results are based on relative changes between different task conditions and, thus, do not provide direct evidence for or against recruitment of totally new brain regions for the naming of novel items. At any rate, the present functional neuroimaging data suggest a higher engagement of regions that in earlier imaging studies have been related to semantic and phonological control processes.
2. Within the predominantly left hemispheric cortical network, retrieval of newly learned words can be accomplished in different ways, depending on the exact form of training. We observed that within the left hemispheric regions related to name retrieval, training effects vary even when the same functional neuroimaging method is used. Cornelissen et al. (2003, 2004) identified training-sensitive left inferior parietal sources, whereas in the Hultén, Vihla, et al. (2009) study, training effects were observed in left fronto-temporal sources. This discrepancy may be related to task demands, as in the Cornelissen et al. (2004) experiment the participants had to learn only the object names, whereas Hultén, Vihla, et al. required that both the names and the definitions had to be acquired. It could thus be that in the former experiment, the subjects based their learning mainly on direct visual-phonological associations (hence a training-sensitive source in an area related to working memory function), whereas in the latter one, word retrieval took place via semantics (hence the left fronto-temporal training-sensitive sources). If this were the case, the latter group acquired the object names in a more natural fashion and could possibly have outperformed the former participants if their long-term maintenance of the words had been compared. This issue also highlights the complexity of the AFE paradigm that at first sight may seem like a very straightforward task.

3. Episodic memory mechanisms subserved by hippocampal structures are related to word acquisition rather than long-term maintenance of newly learned words. The study by Grönholm-Nyman et al. (2010) shed light on the role of episodic memory in the acquisition of new active vocabulary. Although MCI and mild AD patients were impaired in learning to name the novel items, the slope of the forgetting curve of the MCI group and even that of the AD group did not differ from that of the controls. One could argue that the slope of forgetting in the AD patients is confounded by a floor effect, but this cannot be the case for the MCI group, which could recall 54% of the target names at the end of training. As the episodic memory impairment in amnesic MCI is linked to hippocampal dysfunction (e.g., Grönholm-Nyman, 2009), these results suggest that the episodic memory system subserved by hippocampal structures plays an important role in the acquisition of new active vocabulary, whereas long-term maintenance of newly learned words is related to left hemispheric cortical networks. One should also note here that none of the neuroimaging studies with the AFE paradigm has probed the learning (encoding) phases where hippocampal activity could have been captured (cf. also Breitenstein et al., 2005).
4. **Explicit learning and maintenance of novel words can be facilitated by neuropsychological manipulation that boosts the dopaminergic system.** In order to more fully understand the brain systems underlying word learning, knowledge of the neurotransmitter systems involved is also needed. Pharmacological manipulation by dextroamphetamine in normals has recently been shown to facilitate explicit learning and maintenance of new names (Whiting et al., 2007). This drug enhances the release of catecholamines in the nerve terminals and is thus not specific to one neurotransmitter system, but it is likely that its cognitive effects are mediated by the dopaminergic system. Ascending dopaminergic pathways innervate prefrontal areas, and the system has been related to attentional and working memory functions (Nieoullon, 2002). As suggested by Whiting et al. (2007), the observed facilitation in word learning may be related to enhanced working memory and/or memory consolidation.

5. **Neural events following completed training may predict long-term retention of newly learned words.** Very recent results from our research group indicate that long-term maintenance and forgetting of newly learned words could be predicted by the evolvement of left hemispheric naming-related activation 1 week after the training. Currently, it remains unclear which neural events underlie these postlearning changes and which posttraining time window they occupy. However, these results are intriguing, as they may open some new ways to study the interface between language and long-term memory in more natural language learning contexts.

**References**


