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# The nature of the language input affects brain activation during learning from a natural language

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Artificial language studies have demonstrated that learners are able to segment individual word-like units from running speech using the transitional probability information. However, this skill has rarely been examined in the context of natural languages, where stimulus parameters can be quite different. In this study, two groups of English-speaking learners were exposed to Norwegian sentences over the course of three fMRI scans. One group was provided with input in which transitional probabilities predicted the presence of target words in the sentences. This group quickly learned to identify the target words and fMRI data revealed an extensive and highly dynamic learning network. These results were markedly different from activation seen for a second group of participants. This group was provided with highly similar input that was modified so that word learning based on syllable co-occurrences was not possible. These participants showed a much more restricted network. The results demonstrate that the nature of the input strongly influenced the nature of the network that learners employ to learn the properties of words in a natural language.



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## 1. Introduction

When a language is unfamiliar to a listener, it is often not obvious initially where one word ends and another begins in continuous speech. Only a small percentage of words are uttered in isolation (about 9% based on reports by Brent and Siskind (2001) and Fernald and Morikawa (1993)). More typically, multiple words are heard as a nearly continuous speech stream. The ability to detect individual words in running speech is a fundamental early requirement for language acquisition.

In the last two decades, experimental studies grounded in learning theory have suggest that the ability to segment words in running speech is a product of a more general tendency of listeners to track regularities (Gómez, 2006; Newport & Aslin, 2004; Saffran, 2003). In particular, a statistical learning framework proposes that learners track distributional information in their environment and use that information to extract structure and principles about the sensory input they receive. This learning is considered unguided, in that it is not necessary to focus learners on particular aspects of the input and learning occurs in the absence of overt feedback. This tendency to attend to distributional information is not limited to language input, but is general to many types of stimuli including visual symbol sequences (e.g., Reber, 1967; Turk-Browne, Jungé, & Scholl, 2005) and arrays (Aguilar & Plante, 2014; Fiser & Aslin, 2002), environmental scenes (e.g., Brady & Oliva, 2008; Fiser & Aslin, 2002; Turk-Browne, Scholl, Johnson, & Chun, 2010) and tactile sequences (Conway & Christiansen, 2005). The ability to track statistical information allows learners to extract regularities that can be represented as conceptual units. In the case of language, these conceptual units can define word boundaries, as well as grammatical relations within and between words.

Early evidence supporting this general theory comes from studies of word segmentation by infant learners. Infants can segment words from an artificial language by tracking the transitional probability of syllables in running speech (e.g., Aslin, Saffran, & Newport, 1998; Graf Estes, Evans, Alibali, & Saffran, 2007; Saffran, Aslin, & Newport, 1996; Thiessen, 2010; Thiessen & Saffran, 2003). In these types of experiments, high transitional probabilities among sequential syllables predict the presence of multisyllabic words whereas low transitional probabilities reflect the boundaries between words. Transitional probabilities are a more refined statistic than simple co-occurrence frequency, in that the former takes the base frequency of individual syllables into account.

The ability to extract even a few words from running speech further assists the identification of additional words (Bortfeld, Morgan, Golinkoff, & Rathbun, 2005; Cunillera, Càmara, Laine, & Rodríguez-Fornells, 2010). Indeed, some have suggested that the ability to track transitional probabilities to segment words from running speech provides the learner with information about phonotactic constraints, which further serves the process of word identification (Adriaans & Kager, 2010). Because morphemes (including words) form the basis of higher order linguistic generalizations, the initial process of word segmentation is a critical first step to discovering the structure of a language.

Although statistical learning of word forms was first described in infants using artificial languages, similar studies have demonstrated that adults can also use transitional probabilities to segment words from running speech. Such learning appears to be age-invariant, with robust performance reported for older typically-developing children (Evans, Saffran, & Robe-Torres, 2009; Saffran, Newport, Aslin, Tunick, & Barrueco, 1997) and adult learners (e.g. Cunillera et al., 2009; De Diego Balaguer, Toro, Rodriguez-Fornells, & Bachoud-Lévi, 2007; Saffran, Newport, & Aslin, 1996; Saffran et al., 1997; Thiessen, 2010) as well as infants.

The artificial languages typically used in statistical learning studies can be criticized because they are dissimilar to natural languages in several important respects. Artificial language paradigms have typically used strings of consonant–vowel (CV) triplet pseudo-words that recur with high frequency and high density within the artificial language. For example, Aslin Saffran, and Newport (1998) used a four-item nonword corpus where each nonword occurred 45–90 times. This is strikingly different from natural languages, in which most words are not repeated within a sentence and certainly repeat less frequently across sentences than they do in artificial languages. Furthermore, the CVCVCV nonwords used in previous artificial language studies reflect a much more restricted word form than occurs in natural languages. There is evidence that artificial languages in which word forms are more similar to