Acta Psychologica 149 (2014) 1–8

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/ locate/actpsy

New evidence for chunk-based models in word segmentation

Pierre Perruchet [a,*], Bénédicte Poulin-Charronnat [a], Barbara Tillmann [b], Ronald Peereman [c]

[a] Université de Bourgogne, LEAD/CNRS, UMR5022, Pôle AAFE, 11 Esplanade Erasme, 21000 Dijon, France
[b] CNRS, UMR5292, INSERM U1028, Lyon Neuroscience Research Center, Auditory Cognition and Psychoacoustics Team, Université of Lyon I, Lyon, France
[c] Laboratoire de Psychologie et Neurocognition, CNRS UMR5105, Université Grenoble Alpes, Bâtiment Sciences de l'Homme et Mathématiques, BP47, 38040 Grenoble Cedex 9, France

ARTICLE INFO

Article history:
Received 24 June 2013
Received in revised form 23 January 2014
Accepted 27 January 2014
Available online xxxx

PsycInfo-codes:
2340
2343
2346

Keywords:
Word segmentation
Chunking
Modeling
Artificial language

ABSTRACT

There is large evidence that infants are able to exploit statistical cues to discover the words of their language. However, how they proceed to do so is the object of enduring debates. The prevalent position is that words are extracted from the prior computation of statistics, in particular the transitional probabilities between syllables. As an alternative, chunk-based models posit that the sensitivity to statistics results from other processes, whereby many potential chunks are considered as candidate words, then selected as a function of their relevance. These two classes of models have proven to be difficult to dissociate. We propose here a procedure, which leads to contrasted predictions regarding the influence of a first language, L1, on the segmentation of a second language, L2. Simulations run with PARSER (Perruchet & Vinter, 1998), a chunk-based model, predict that when the words of L1 become word-external transitions of L2, learning of L2 should be depleted until reaching below chance level, at least before extensive exposure to L2 reverses the effect. In the same condition, a transitional-probability based model predicts above-chance performance whatever the duration of exposure to L2. PARSER's predictions were confirmed by experimental data: Performance on a two-alternative forced choice test between words and part-words from L2 was significantly below chance even though part-words were less cohesive in terms of transitional probabilities than words.

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1. Introduction

Language acquisition initially proceeds from auditory input, and linguistic utterances usually consist of sentences linking several words without clear physical boundaries. The question thus arises: How do infants become able to segment a continuous speech stream into words? Recent psycholinguistic research has identified a number of potentially relevant factors. Analyses of natural languages have shown that a number of acoustical, prosodic, and statistical features are correlated with the presence of word boundaries, and could therefore be used as cues for segmenting the speech signal into words. There is large evidence that these cues are used at a various extent according to the age of the learners and the specific structure of the language (Thiessen & Saffran, 2003), and that they interact in complex ways (Creel, Tanenhaus, & Aslin, 2006; Onnis, Monaghan, Richmond, & Chater, 2005; Perruchet & Tillmann, 2010).

In this paper, we focus on statistical cues, such as they were revealed in the seminal studies by Saffran and collaborators. For instance, Saffran, Aslin, and Newport (1996) used an artificial language consisting of four trisyllabic words, such as *golatu* and *daropi*. In the familiarization phase, 8-month-old infants listened to a sequence of words, which were read by a speech synthesizer in random order in immediate succession, without pauses or any other prosodic cues. In the following test phase using a familiarization-preference procedure, the infants were presented with repetitions of either words or trisyllabic "part-words", such as *tudaro*, consisting of the final syllable of a word joined to the first two syllables of another word. Infants showed longer listening times for part-words, suggesting that they were perceived as novel sequences. This and other studies (e.g., Aslin, Saffran, & Newport, 1998) are usually interpreted as indicating that infants exploit the transitional probabilities (TPs) between syllables, because word-internal TPs are stronger than TPs between the syllables that compose the part-words (i.e., containing word-external TPs).

1.1. Two competing hypotheses

The prevalent interpretation for this remarkable outcome is that participants perform statistical computations (e.g., Aslin et al., 1998; Endress & Mehler, 2009). The reasoning is straightforward: If learners' behavior turns out to be sensitive to a given statistical property of the input, then this implies that learners somehow compute the relevant statistics. Typically, learners are assumed to compute the TPs between successive syllables (Saffran, Newport, & Aslin, 1996). In a competing approach, the sensitivity to statistics is a mandatory consequence of the engagement of other cognitive processes. Instead of inferring the words from the prior computation of TPs, the general strategy shared

* Corresponding author at: Université de Bourgogne, LEAD/CNRS, Pôle AAFE, 11 Esplanade Erasme, 21000 Dijon, France.
E-mail address: pierre.perruchet@u-bourgogne.fr (P. Perruchet).

http://dx.doi.org/10.1016/j.actpsy.2014.01.015
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by all chunk-based models is that many potential chunks are created, then selected as a function of their relevance (e.g., Brent & Cartwright, 1996; Frank, Goldwater, Griffiths, & Tenenbaum, 2010; Perruchet & Vinter, 1998; Robinet, Lemaire, & Gordon, 2011; Servan-Schreiber & Anderson, 1990).

Although relying on very different processes, the two accounts coined hereafter as the *TP-based* approach and the *chunk-based* approach, respectively, appear to be surprisingly difficult to dissociate. We propose below an experimental design leading to contrast the predictions of these two approaches. Before introducing to this new design, however, a finer description of the chunk-based model that will be considered here, namely PARSER (Perruchet & Vinter, 1998), is in order.

1.2. PARSER model

Let us consider the famous Saffran, Newport et al. (1996) study in which six trisyllabic words, *babupu*, *bupada*, *dutaba*, *patubi*, *pidabu*, and *tutibu*, were repeated in random order. The speech flow may begin as:

(1) *babupututibubabupudutabapatubibupadapatubidutabababu pupidabu*…

PARSER postulates that (1) will be perceived as, for example:

(2) *babu putu ti buba bupudu ta bapa tubi bupada pa tubi duta bababu pupi dabu*…

where spaces stand for subjective boundaries. These boundaries are introduced as a consequence of attentional mechanisms, which naturally segment the sensory input into small disjunctive parts of various lengths. [1] The randomly determined fragments are created as provisional chunks as they appear in the language. Clearly, a few of them are relevant to the structure of the language (*bupada* is a word, and *babu*, *tubi*, and *duta* are components of words) and others are irrelevant. How does the model operate a selection without calling to sophisticated computations? In PARSER, the fate of a new chunk depends on the probability for this new chunk to be encountered later. The relevant units emerge through a selection process based on forgetting, which leads to eliminate the less cohesive parts among all parts generated by the initial chunking of the material. For instance, *bababu* is doomed to forgetting, because it will reoccur only when *dutaba* is followed by *babupu*. By contrast, *babu* and *bupada* have more chance of resisting to forgetting because they will be strengthened on each occurrence of *babupu* and *bupada* respectively, whatever the surrounding words.

Forgetting, in PARSER, is the end-product of both decay and interference. If forgetting was only due to decay, PARSER would be only sensitive to the raw frequency: The candidate units resisting to forgetting would be those that occur the most frequently in the speech flow. Interference allows the model to be sensitive to more sophisticated measures of contingency. To illustrate, *putu*, which straddles a word boundary, has been processed as a unit in (2). The weight of this unit will be decreased each time another interfering unit will be perceived. This is the case with the units *bupudu* and *pupi* in (2), because *pu* is present and followed by another syllable as *tu*. The resulting effect is nothing else here than the classical effect of retroactive interference, whereby learning AC has a more detrimental influence on the retrieval of a previously learned pair AB than learning a list of unrelated items (e.g., DE). It is clear that, overall, *putu* will receive more interference than a within-word component, given that *pu*, as a final syllable of a word, may be followed by several different syllables. This example illustrates that increasing the sources of interference and decreasing TPs are two sides of the same coin, because both result from an increased number of possible adjacent events (Perruchet & Poulin-Charronnat, 2012a). As a consequence, implementing interference as a mechanism of chunk selection in PARSER makes the model responsive to TPs.

Crucially, once a new chunk has been created on the basis of its internal consistency, it plays the role of a new primitive, which constrains the coding of the incoming information as did the initial primitives (i.e., the syllables). For instance, once *bupada* has been built as a perceptual primitive for the model, the following percept necessarily begins with the following word, hence increasing the probability of discovering this word (i.e., *patubi* from (1)). In this way, PARSER naturally accounts for the fact that known words help to discover new words (Bortfeld, Morgan, Golinkoff, & Rathbun, 2005; Dahan & Brent, 1999), as analyzed in Perruchet and Tillmann (2010).

1.3. The present study

The rationale of the present study directly follows from the principle stated just above. We noted that knowing *bupada* helps to discover *patubi* when exposed to *bupadapatubi*. However, a more general claim is that the probability of creating a new unit depends on the units already present in the lexicon, *whether relevant or not*. If *dapa* has been created, this will trigger the formation of chunks such as *bupa* or *tubi*, which are not words, when exposed to *bupadapatubi*. More generally, if a wrong unit has been created, this will trigger the formation of other wrong units. This happens only rarely in natural settings, given that decay and interference tend to select the relevant units (i.e., the words) of the language. But the phenomenon can be artificially induced in controlled conditions through the prior presentation of irrelevant units. This offers the opportunity of manipulations leading to predict opposite effects in a chunk-based framework and in a TP-based framework, which does not exploit such a principle.

In keeping with this strategy, the present study examines how familiarization with a first language, L1, affects the segmentation of a second language, L2. In the following experiment, L2 was composed of three trisyllabic words, ABC, DEF, and GHI (each letter stands for a syllable), which were randomly concatenated without immediate repetition. L1 was composed of bisyllabic words, which were played as isolated utterances. In the main experimental condition (the *overlapping* condition), the words of L1 reoccurred as word-external transitions in L2 (e.g., *CD* occurred in L2 when *ABC* was followed by *DEF*). In a *control* condition, the pairs of events composing the words of L1 never occurred in L2 (e.g., *CA* could not occur, because repetitions of words were not allowed). In a subsequent two-alternative forced choice (2AFC) test, participants were exposed to pairs composed of a word and a part-word of L2 (see Table 1). For each pair, participants had to decide which item seemed more like a word of the imaginary language they were exposed to before.

The underlying intuition was that a TP-based approach should predict above-chance performance in the 2AFC test, whatever L1. This is because, as shown in Table 1, none of the pairs of syllables played in L1 was included in the test items, whether words or part-words, and this was true for both the overlapping and control conditions. PARSER should also predict above-chance performance in the control condition. Indeed, because the chunks built from L1 are no longer present in L2, they will be progressively forgotten, and learners have only to build new chunks from L2. However, crucially, L1 chunks continue to be perceived during L2 presentation in the overlapping condition, and because they are between-word transitions in this new context, they could misguide the segmentation of L2, as explained above. As a consequence, the score in the overlapping condition should be lower than the score in

[1] Certainly the subjective experience of the beginning listeners would be rather the perception of a continuous and unintelligible speech flow, from which a sequence of a few syllables pops out from time to time. This does not change the rationale of the model. Simulations have shown that PARSER was able to reproduce the performance of actual participants while processing only 3 to 5% of the syllables of the languages (Perruchet & Vinter, 1998, Study 2). For instance, only *putu* or any other bisyllabic items may have popped out from Sequence (1), without hampering the ability of the model to account for human performance.

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