The Role of C-Cluster Probabilities in Non-Word Storage: Evidence from a Serial Recognition Task.

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Abbreviations:

C…………….Consonant
DM…………declarative memory
L1……………native language
L2……………foreign language
LTM…………long-term memory
MOP…………Maximum Onset Principle
NOCODA……..No-Coda constraint
PM…………...procedural memory
OT……………Optimality Theory
RT……………reaction time
STM…………short-term memory
SSP…………..Sonority Sequencing Principle
V……………..Vowel

A. Introduction

This research focuses on *phonotactics* that influences acquisition and processing: it is used for segmenting speech and building up the *mental lexicon*. *Phonotactics* is a branch of phonology that deals with restrictions on possible sound combinations within a language. It defines phonotactic constraints that govern syllable structure, consonant clusters, and sound sequences in general by determining which sequences of phonemes may follow each other within syllabic constituents. In short, in the same way as syntax restricts phrases, phonotactics restricts syllables. Syntax defines all possible phrases of a certain language; phonotactics defines all possible words.

Phonotactics could either be represented on the *lexical* or *sub-lexical level*. The *lexical level*, also metaphorically named the *mental lexicon* is the place, in which we store words and according to some processing models also affixes and inflectional morphemes. These lexeme entries are connected to information about semantic representations, the lexical category, syntactic properties, morphological properties and internal structure, and the phonological representation. All this information has to be understood and saved in the mental lexicon during the language acquisition process.

Language processing models however usually propose two levels of processing. In perception[1], before the mental lexicon is accessed first all phonetic and phonological information is processed at a *sub-lexical level*. Here, the basic representational units of the morpho-phonological sound string, thus all properties and categories that are encodable from the acoustic input, so phonetic features, syllable properties, prosodic information and morphology are processed.

How much information is processed sub-lexically, is controversial. Bi-phones or larger phoneme sequences have often been claimed to play no role in processing as perceptual units. Language would be processed on two levels only then: one level would store lexical information, and on the other only the phonetic information given in the surface representations of the input would be processed (e.g. Curtis et al. 1998, Marslen-Wilson 1999). Recent studies however state that also phoneme clusters could be perceptual units and processed categorically just like singleton phonemes (e.g. Halle et al. 1998, Vitevitch & Luce 1999).

[1] This work will concentrate on perception, thus production will not be dealt with.

Once the sound string is encoded sub-lexically, the information passes on to the lexical level, where words and bound morphemes are stored. These lexical representations are linked to phonological and semantic information: form and meaning. The semantic connections inform about abstract representations of word meanings, including denotation and connotation, and syntactic constraints.

Optimality theory (OT) describes phonotactic knowledge and how syllables are structured with universal constraints. The constraints per se are universal. During acquisition, they are ranked in a language specific hierarchy. Constraints which are not "used" in a specific language will still be present in the hierarchy. However, they will only occur at a very low position in the ranking, and thus not have an effect on processing. Thus, OT constraints differ from parameter set rules. They will always be in the ranking and they may even be violated and still deliver the optimal output candidate.

To give an idea of what these constraints look like, some will be introduced here. Among the most important, with which syllable processing needs to be defined preliminarily, are the Maximum Onset Principle (MOP), the No-Coda constraint (NoCoda) and the Sonority Sequencing Principle (SSP). MOP expresses the universal rule, due to which phoneme sequences are syllabified in a manner that the coda will be as empty as possible. NoCoda disallows branching rhymes in general. SSP expresses that syllables should be structured hierarchically, with its most sonorant segment building the nucleus and falling sonority versus the edges.

The constraints by which phonemes may co-occur in a language, need to be acquired, in L1 and L2, respectively. I will give an example to illustrate this idea. In the Dutch syllable template for example, onsets and codas may be branching (Trommelen 1983); yet how the consonants may be arranged is restricted to the sonority hierarchy: the consonants closer to the nucleus, which is always occupied by the most sonorous element of the syllable, have to be the more sonorous. So, Dutch allows a sequence of /tr/ within one syllable, inside an onset, but not in a coda. The cluster /tl/ though is not legal in Dutch, though phonetically these two clusters highly resemble each other, and no formal reason can account for the non-existence of the latter. Modern Hebrew however allows for both sequences, whereas Modern Farsi for example allows neither /tl/ nor /tr/. Farsi disallows branching onsets, but allows branching codas, and though it is not bound to the sonority sequencing principle, the clusters are neither legal in coda position. Russian on the other hand allows both branching onsets and codas and on top of that is not restricted by the sonority sequencing principle. Both /tr/ and /tl/, not surprisingly, are legal in syllable initial and final position. Japanese on the contrary does not allow consonant clusters at all.[2]

The three constraints are ranked differently language-specifically. NOCODA for example will be ranked higher in Japanese than in Modern Hebrew. Also Dutch, Farsi and Russian will have NOCODA in their ranking, but at a much lower level, because it gets violated very frequently. The SSP constraint will be ranked quite high in Japanese, Dutch, Modern Hebrew; in Farsi and especially in Russian, SSP will be ranked very low. The MOP constraint must be high ranked in Japanese, and Modern Hebrew, but lower in Dutch, Russian, and particularly low in Farsi.

This example shows how different languages can be structured in terms of their sounds. These differences do not only strongly characterize a language; they also play an important role in language processing. This is for example revealed in slips of the tongue, which never violate phonotactic restrictions (Fromkin 1971). Thus, phonotactic constraints and their rankings have to be learned. It has been shown that they are acquired at even very early age: 9-month-old children are able to distinguish between native and nonnative phonotactics (Jusczyk et al. 1993), and are even sensitive to probabilistic varieties among the sequences. The tested infants showed longer listening-times to nonwords composed of high probability phonotactics than to low probability phonotactic nonwords (Jusczyk et al. 1994). It is known, that phonotactic knowledge contributes important cues for speech segmentation (McQueen 1995; 1998; van der Lugt 1999), and it seems that 8-month-old infants already are sensitive to probabilities in co-occurrences of syllables in nonsense strings, which might be an important cue for speech segmentation (Saffran et al. 1996b). Jusczyk, Luce, and Charles-Luce (1994) further supposed that phonotactics are acquired so early, because they might be used for the creation of lexical entries. Children need to develop knowledge of where potential word boundaries are. Only then they can acquire words. Moreover, expected phonotactic shapes of words support the child's lexical acquisition (Gathercole et al. 1999; 2001; Storkel & Rodgers 2000; Storkel 2001).

Whether phonotactics as in the L1 are also used in L2 lexical acquisition, will be a researched in my PhD project. With this MA thesis, I aim at introducing the questions that need to be raised to conduct this research.

An important factor is that it needs to be known, whether the *phonotactics* that is spoken about is grammatical or lexical knowledge. In theory, probabilistic

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[2] Obstruent-glide combinations are exceptions.

phonotactics could either be represented sub-lexically as phonological grammar, or it could be abstracted from the mental lexicon in phonological chunks. Current research offers both explanations, and it is likely that both sources are used in processing (e.g. Bailey & Hahn 2001). These will be discussed under detail in chapter B. General aspects about formal grammar and its psychological reality will be introduced, a formal description of the character of linguistics will be given, and the mental representation of phonotactics will be discussed.

To carefully define, where phonotactic knowledge is mentally represented is important for research on L2 lexical acquisition. New research clearly states that adult L2 learners have problems acquiring non-native grammar (Ullman 2005). This leads to some interesting predictions about phonotactic L2 learning. If phonotactics have a grammatical component, and this grammatical knowledge is essential for lexical acquisition, the learner will be faced with a serious problem. The degree of this relevancy will be discussed in chapter C.

An experiment was designed and conducted, which is described in C.2. This experimental investigation had two central aims. The first was to show whether phonotactics have a grammatical component. The second was to find a task which would reveal an involvement of phonotactics in processing and could be used for future research with L2 learners.

Chapter D. gives an overview over the findings of this MA thesis and throws a glance at future perspectives.

B. Phonotactics – grammar or lexicon?

The consideration how language is acquired, mentally processed, how words are stored and accessed, has led scientists to diverse theories and models.

In this chapter, the most influential and dominant hypotheses about whether learning and processing is based on statistical knowledge, on innate grammar or both, will be introduced. Special focus will be put on phonological processing and the issue of where phonotactic knowledge is represented.

Whether language processing depends on statistical analysis, the calculation of algebraic rules, or both, is a very important issue for the science of linguistics, and at the same time challenging. In general, all three options are plausible and defendable, whereas the third, to view processing as an operation combining the two strategies is quite new. Whether rule abstraction needs to be traced back to an innate grammar, as generative grammar proposes, or whether these rules can be learned, we do not know yet, though the innate view is most propagated, and only very few researchers work on bringing empirical evidence for a rule-learning device (e.g. van Kampen 1997).

In section 1., the three different views on the mental reality of grammar will be introduced. That phonotactics is grammar, but to a large extent builds up on statistics, is discussed in section 2. Section 3. is about the mental representation of phonotactic knowledge. Section 4. discusses the research background and introduces an own hypothesis. A summary will be given in 5.

1. Different views on the psychological reality of grammar

About how and whether grammar has a psychological reality, three views are defended in linguistic literature. The classical generativist model is going back to Chomsky (1968). It assumes linguistic knowledge to be generated by rules and represented in modules. Input information is sent bottom-up from one module to the next, until the message is encoded. The modules are autonomous, and do not interact with each other. This idea bases on the notion that human language is a complex symbolic system, computable via a defined number of rules. Language is mentally represented in decomposable units, which are stored in modules. Syntactic, morphological, phonotactic and phonological units are the building blocks of which language is composed. The units are sensitive to structure and any time language is processed, these units are paradigmatically inserted in constituent structures (Fodor & Pylyshyn 1988:13).

Technical improvements changed the cognitive sciences. Cognitive processes and spreading activation as it was assumed for neuronal structures could now be simulated in abstract computer networks. While modular models propose constituents that are inserted in symbol structures, connectionist models generally do not support the idea that words and sentences are parsed into smaller linguistic units. Only for practical purposes they sometimes use such units, but generally they assume many connected units or nodes that spread parallel and interactive activation, and trigger inhibition processes. The first important connectionist model is the PDP model. With this model it could be demonstrated that computers do not need symbolic rule representations to generalize regular inflectional morphology (McClelland & Rumelhart 1986). In connectionist models (e.g. Schade 1999), linguistic units are not represented in modules, but in nodes, which are connected via links. Two connected nodes can interact and thus influence and accelerate the activation of a word, because single modules do not need to be searched one after the other, but access is simultaneous (Schade 1999:73).[3] Words are thus not represented by distinct linguistic units and constituents, but by activation patterns, which are distributed over nodes like brain activation is distributed in neurons. All our lexical knowledge is represented in connections between nodes. The connections between nodes change continuously in life, sometimes in a way that does not have an effect on language use, but sometimes in a way that could change processing strategies (e.g. Schade 1999).

The interactive activation goes as follows: nodes are linked via connections. When a node is activated, it tries to pass its activation on to neighbor nodes. Every node has a certain resting activation value. The more frequently a node is activated, the higher is its resting activation value. If a node is not accessed for a while, its activation value decreases. Immediately after a node is accessed, its activation value is at maximum. A node will be selected, if the activation value is higher than the selection threshold value. Also more than one node can be activated simultaneously. In general, multiple nodes try to send their information

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[3] This is a big advantage of connectionist models over modular models. A human stores hundreds and thousands of symbols. If these always would have to be searched serially, it would cost too much time (Fodor & Pylyshyn 1988:4).

to the next processing level, but only the node with the highest activation value will be chosen. Spreading activation starts from the input string by analyzing the phonetic features. From there, phonemes get activated, which in turn activate syllables that activate the words, which are linked to the semantic concepts. Spreading is symmetrical. That means that information flows backwards also (Schade 1999:24-25).

There are important recent usage-based approaches, which argue against rules that are used to generate syntax or morphology. They propose analogical learning motivated by the wish to communicate (e.g. Tomasello 2003, Bybee 1995).
What probably comes closest to the way language is really processed are those models that try to combine connectionist ideas of spreading activation dependent on type and token frequency and parallel processing with a computing power that makes use of rules and structure. Pinker (1991) was the first to combine the advantages of both, the Chomskian rule approach (1964) with the Connectionist ideas by Rumelhart and McClelland (1997). He proposes that irregular words are stored as whole items in the mental lexicon, whereas regularly inflected words are generated by rule from their separately stored constituents. Brain imaging studies support this view. Different brain areas are active in processing for example irregular and regular inflected verbs (Ullman 2005).

A very interesting acquisition model that builds onto Pinker's model is the declarative/procedural model proposed by Ullman (2005). It differs from classical SLA accounts, not only because of its independence of area: The assumptions are a result of a series of neurocognitive studies using cognitive, computational, anatomical, physiological, cellular, and molecular investigations using ERP, PET, fMRI, and hormone value measures.

The D/P model is based on neurolinguistic studies, which have shown that two different memory systems are active in language learning and processing: the procedural memory (PM), and the declarative memory (DM). The DM, located in the medial temporal lobe, connected with temporal and parietal neocortical regions, is responsible for processing facts and events. Knowledge processed here is both, explicit and implicit. The PM processes the learning and control of the cognitive motor skills, is specialized on sequences and regularities. It shows activation in the left cerebrum, neural circuits that encompass the frontal lobes and basal ganglia, strong connections to frontal cortex (Broca’s + Pre-motor area). All knowledge processed here is implicit only.

These two memory systems fulfill different functions in processing and acquiring language. Learning of lexical knowledge as word learning of both the phonological form and the meaning depends on the DM, whereas the learning of combinatorial grammar, the detection of hierarchical structure in morphology, syntax and possibly also phonology, depends on the PM. The storage of the phonological form of words, on which focuses this thesis, is interestingly located in a sort of interface area in the superior temporal and temporo-parietal regions, which are also used for storing morphologically complex words (2005:149).

The main findings that support the D/P model for L1 acquisition and processing are a predominant involvement of the medial temporal lobe in processing of facts and events (DM), and an activation of Broca's area, the basal ganglia, and the left cerebrum in processing grammar as in syntax and transparent morphology (PM).

These two memory systems are not domain specifically responsible for language acquisition and processing. Also non-linguistic knowledge is processed here: The DM is active in processing facts (semantic) and events (episodic) and learning of arbitrary relations, thus mainly explicit, but also implicit knowledge. The PM is involved in learning and controlling the cognitive motor skills, especially when it comes to memorizing sequences, thus implicit knowledge.

In L2 acquisition, in the initial periods mainly the DM is active. This does not only hold for vocabulary learning. Also L2 grammar, no matter how transparent, is learned and processed explicitly by the declarative memory. This is different from L1 acquisition, where the procedural memory is involved right from the start. Only very close to ultimate attainment, the PM becomes active. In an L2, a strong correlation was found between age and the participation of the PM. The older the L2 learner gets, the less the procedural memory supports the acquisition. The DM activation however does not differ from L1 to L2 learning. In plain words, an L2 seems to be learned consciously, whereas an L1 to a big extent is learned unconsciously. This explains why late learning of an L2 often does not cause equal problems for the acquisition of new lexical items as for grammar. It seems that humans loose their rule-abstraction abilities very early. Principles and Parameters theory argues that once parameters are set, it is impossible to shift them. This would mean that L2 learners simply do not have any access to UG principles after a critical age. Connectionists would then argue that also other motor skills like the capability of learning to ride a bike become reduced with increasing age.

Apparently L2 learning is mostly based on reliance on the DM. Even complex linguistic forms and rules are learned consciously. Only with lots of practice the PM experiences a stronger involvement.

For this work, I take the Pinkerian division of grammar and lexicon as a baseline. This leads to different assumptions about acquisition dependent on the origin of phonotactic knowledge. Phonotactics have been described as both, knowledge which is stored within lexical units in the mental lexicon, and as grammatical knowledge represented sub-lexically by constraints. If it were lexical knowledge, it would be acquired by rote, and if it were sub-lexical knowledge, it would be acquired by rule.

In the next chapter it will be explained in more detail why this distinction and the clear definition of the source of phonotactic knowledge are so important, if one speaks about its acquisition. Before that in the next section it will be discussed, to what extent phonotactics must be viewed as grammar, and to what extent as associative statistical knowledge from a formal perspective.

2. The nature of phonotactics

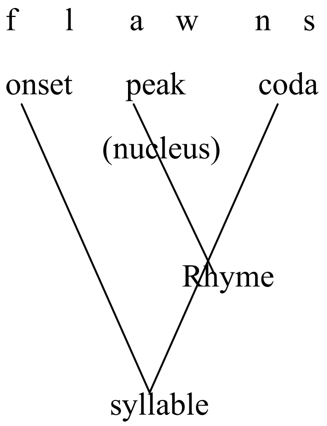
In classical generativist approaches the syllable has been viewed as a grammatical linguistic unit governed by internal rules. More recent approaches acknowledge that statistics about co-occurrences of phonemes carry important information for the speaker. In this section will be discussed, how much stable grammar and how much statistics are involved in phonotactics.

2.1. Phonotactics is grammar

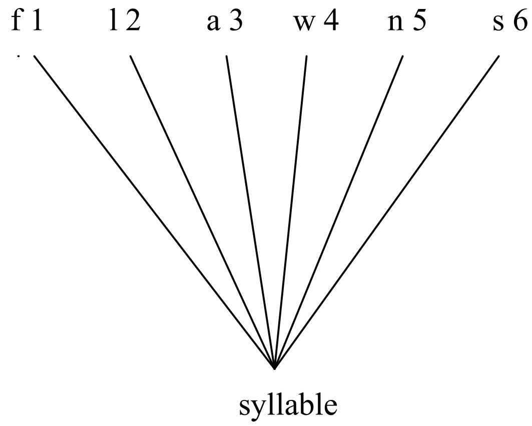
That the syllable is one of the core units in language processing has been ignored a long time. However, nowadays it becomes more and more certain, that the syllable carries information that is mentally stored and used for speech processing and speech segmentation. The most convincing arguments for regarding the syllable as a linguistic unit have been raised by Selkirk (1982). For example, for English she shows that syllables have an internal structure.[4]

[4] The issue that syllables do have a structure was not raised by Selkirk herself, but she came up with some salient arguments for considering syllables as constituents that have an internal hierarchical structure. Pike (1967) and Lehiste (1971) for example also state an internal constituent

Theoretically, syllables could be phonologically represented in two ways:



or



(1) Hierarchical structure representation

(2) Linear representation

The two figures show the structuring of the monosyllabic word *flounce*, pronounced as /flawns/. This syllable contains six phonemic segments that could either be a sequence of segments without hierarchy, defined by their boundaries as in (2)[5], or they could form a constituent with an internally structured tree hierarchically organized as in (1). In the latter, the segments are ordered binary in a hierarchical manner. The onset containing the initial consonant cluster is divided from the rhyme, containing the rest. The rhyme can be sub-divided into nucleus, usually consisting of the vowels, and the coda, comprising the final consonant cluster.

This structure goes back to Pike (1967 in Selkirk 1983:329) who found that for example in a CCV sequence the nature of the intermediate C is generally restricted by the initial C and not by the preceding V. This shows that a stronger connection prevails between two consonants next to each other than between a consonant and a vowel. Different from the linear representation (2) the hierarchical structure under (1) expresses this. For this reason, the syllable generally is viewed as a linguistic unit that can be broken into smaller units, namely onset, nucleus and coda, which are governed by the strictest phonotactic rules.

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structure, and Liberman (1975) and Liberman and Prince (1977) already describe this internal structure as hierarchical (in Selkirk 1982:347).

[5] Hooper (1976) for example proposes this representation (in Selkirk 1982:330).

In OT, the phonotactic constraints, which take effect inside the syllable and its constituents,[6] are assumed to be universal, but ranked in a language specific manner. Certain characteristics of the syllable structure are emergent in every language, other properties however differ significantly among languages, being legal in one and strictly prohibited in the other. To give an example, every language contains universally minimally a vowel, and obligatorily allows CV syllables.

That the syllable is structured hierarchically is not only approved among theoretical linguists, but also gains support by psycholinguistic investigations. The structured character of syllables is for example revealed in phonological slips of the tongue. Slips always follow a distinct pattern: two onsets can be interchanged, as in 1.a and 1.b, or a nucleus can be reiterated as in 1.c, but a slip in which a nucleus would be substituted by a coda, never occurs.

a. schlecken sie den Stüssel ins Loch ← stecken sie den Schlüssel ins Loch

Stick (– imp) the key   in the hole

b. meine Rigazetten sind leer ← meine Zigaretten sind leer

my   cigarettes are empty

c. die größte Börse der Wölt ← die größte Börse der Welt

the biggest stock-market in the world

(Source: Frankfurter Versprecher-Korpus)

So, misled speech production data encourages the view that possible syllabic constituents are stored as units.

Recent research demonstrates that apparently not only phonotactically legal units are represented, but also illegal sound sequences. A Dutch speaker for example should have a mental representation about the illegality of the onset */mr/ and a storage of /dr/ as legal. Experimental evidence has been brought that this sort of knowledge about position specific legality of sound sequences is used for speech segmentation: Dutch words like *rok* embedded in nonword strings that either align (as in *vidrok*) or misalign (as in *vimrok*) a consonant with the word are easier to

[6] Phonotactic constraints are not restricted to syllables. There are also sequential constraints, for example the OCP constraint, which affects consecutive consonants within words across syllable boundaries.

detect, if the consonant cluster is an illegal onset (McQueen 1998). However, even more than plain positive or negative information about sound sequences seems to be represented. This will be presented in the following section.

2.2. Phonotactics is statistics

A speaker of Dutch will immediately detect the syntactic mistake, if someone uses a verb-final VP in a main clause, because Dutch is a verb-second language. Similarly, he will know straight away that *mrak* is not a Dutch word – for two reasons: First, it does not occur in the lexicon, and second, with /mr/ it contains a phoneme sequence that is illegal in Dutch. This might not seem very special; it is easy to follow that listeners are very aware of what is legal and what is illegal in their language, because anything legal – anything that occurs in the certain language, must be stored somewhere in the mental apparatus. This pertains to grammar and lexicon. However, phonological grammar apparently contains more than that: Also knowledge about illegal sound sequences is represented (compare McQueen 1998).

Newer studies even argue that knowledge of the frequency of co-occurrences of phonemes is represented and used for processing.

That frequency has a relevant impact on processing has been shown in several experimental studies. In lexical decision tasks for example, high frequent words are processed quicker than low frequent words (Segui et al. 1982), also frequency dependent morphological decomposition has been demonstrated (e.g. Chialant & Caramazza 1995:65-66).

Frequency apparently affects mental storage:

> […] In order to capture the fact that words encountered frequently have different properties from words encountered relatively infrequently, all models must assume that accessing a word in some way affects the representation of that word. (Hay 2000:4-5)

Which or whether even every sort of mental entry is equipped with frequency representations, is an ongoing debate in the literature, but in many models frequency is integrated at all levels of processing as an influencing factor on access and storage. Connectionist models, which assume an interactive activation of the various mental entries, give frequency a central role. The more frequent an entry of a unit is, the higher is, because of the regular access, its resting activation value. High resting activation values lead to quicker access of the entry (Schade 1999:18-19).

Already the autonomous serial search model ascribes importance to token frequency in storage. Words and morphemes are distributed in subsets in such a way that in serial search the more frequent entries can be accessed quicker. In this model, lexical access starts at the master lexicon, which is connected with many small access modules, which carry for example syntactic, phonological or semantic information. All modules are searched serially; interactive control is neither possible nor necessary (Taft & Foster 1975).

Frequency is clearly the factor that has triggered the development of the dual route model (Frauenfelder & Schreuder 1991), which still accounts best for morphological parsing. If a morphologically complex word is accessed frequently, the consequence will be a long-term high resting activation value of the complex word as a whole. If the morphological constituents of a complex word have been successfully parsed frequently, the resting activation values of the subcomponents will be higher as the word as a whole. This will even result in a decomposed storage (ibid:177)[7].

Also phonological processing is affected by statistics of frequency. Speakers hark back to frequency distributions of phoneme sequences. Already 9-month olds are sensitive to statistical frequencies about phoneme co-occurrences in the speech stream (Juczsyk et al. 1994) and are able to segment nonsense speech by using phonotactic probability information (Saffran et al. 1996b). In nonword recognition tasks, reaction times for high probability phonotactic nonwords were quicker than for low probability phonotactic nonwords (Vitevitch & Luce 1998, 1999); wordlikeness-judgment ratings for nonwords depend on their phonotactic structure (Bailey & Hahn 2001); and also short-term memory performance is influenced by phonotactic probability, and seems moreover to be related to lexical acquisition (Gathercole et al. 1999; Gathercole et al. 2001; Storkel & Rodgers 2000, Storkel 2001, 2003, Beckman et al. in press.). Experiments demonstrated that high frequent syllables, which do not carry semantic information, but occur in

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[7] Newer more precise studies (e.g. Hay 2000:103; Bertram et al. 2004:326f) show that processing of morphologically complex words is dependent on the relative frequency of its subparts. If the base by itself has a higher token frequency than the complex word as a whole, decomposed access will be a consequence.

polysyllabic real words, yield an implicit priming effect (Cholin et al. 2004), and increase repetition and recall performance (Nimmo & Roodenrys 2002).

The study by Saffran et al. (1996a, 1996b) represents a radical view of phonotactic processing being a pure statistical analysis of frequencies of co-occurrences of sounds, in which no structure is involved. They tested whether statistical knowledge about the probability of co-occurrence of syllables is used for locating word boundaries. An example clarifies their hypothesis: the syllable [beɪ] occurs in many English words, as for example in *baby*, but it also occurs as a word by itself. If the syllable [bi] more often combines with [beɪ] than [beɪ] is used by itself, a realization of the word *baby* will be expected and consequently will be activated faster. A sequence like [beɪ.tu] will be comparably unexpected, but will simultaneously give a strong cue for a word boundary (Saffran et al. 1996a:611). The hypothesis could be proved in an artificial nonword learning experiment. Adults (Saffran et al. 1996a) and 8 month-old infants (Saffran et al. 1996b) were exposed to a continuous speech stream that was composed of artificial CV syllables. Three syllables always occurred in the same order as 123123123 et cetera. The transitional probability between 1 and 2, and 2 and 3 respectively is always =1. Between 3 and 1 though it is = 0.3. It turned out that already 8 month olds use this statistic information to segment speech, and so do adults (Saffran et al. 1996a, 1996b), which led them to the assumption that children are capable to deduce structures from statistical learning without making use of innate grammatical knowledge, as much as they use statistics in music, vision, and other domains.

Many researchers responded to Saffran et al (1996a, 1996b) with follow-up studies. Some of them will be discussed below.

2.3. Phonotactics is both, grammar and statistics

Statistics influence language acquisition and processing. Many linguists and psycholinguists defend that grammar nonetheless plays a determinant role. This has led to the development of hybrid models of a combined use of symbolic rules and representations and statistics. This section provides a discussion of some of them.

Among these were Marcus et al. (1999), who conducted several artificial language learning experiments with infants in order to find out if statistics alone indeed suffice to explain acquisition of grammar. One group of infants was presented with nonsense sentences in an ABA pattern of syllables (e.g. ga ti ga, li na li etc.), the other group with syllables presented in ABB order (e.g. ga ti ti, na li li etc.). These patterns represent symbolic operations, because their occurrence is predictable by rule, and resemble linguistic rules in this manner.

Infants were first trained on 3 repetitions of 16 "sentences", so ABA or ABB strings dependent on the group they were in. After the training, the infants were presented with new sentences in both ABA and ABB patterns. As a result, the infants showed preference for the sentences with the unfamiliar pattern. A follow-up experiment, when ABB strings were compared AAB strings to exclude reduplication as a factor, the results did not change. This study shows that statistical learning alone cannot account for everything and concludes that both, statistics and rule extraction are used in language learning. Whether these learning mechanisms are language specific or general learning mechanisms, is not addressed here.

Follow up studies tried to show that Marcus et al. (1999) were wrong; that one could model the learning effects that revealed in the infants in the experiments in simple recurrent networks. Altmann (2002) showed that these trials were never completely perfect. They all had made use of freezing. That is, they had frozen the weights on the connections in the input layer, simulating an already stabilized grammar. This has the advantages that it forces the network to map test sequences on existing representations, and that new word learning does not change the existing grammar. However, because freezing is unnatural, Altmann introduced two modifications. He pre-trained the network on grammar and vocabulary, which allowed abandoning the freezings of connection weights.

After a pre-training phase on a total of 10 000 sentences, which were then repeated six times, the networks were trained on either 48 ABA or 48 ABB sentences (3x16) exactly as in Marcus et al. (1999). In the final test they fed the network with 12 sequences - both, 6 ABA, and 6 ABB - in order to see, which patterns the network could learn more easily or whether there was a difference, depending on which pattern it was exposed to in advance.

After pre-training, the networks performed better on ABA patterns after having been familiarized with ABA, but without pre-training on ABA patterns they performed better on ABB strings. That is, because adjacent repetitions as in ABB are easier to acquire in general. The result shows that pre-training is necessary for rule detection. The advantage of pre-training seems to be that encoding of structure is learned early. Pre-learning of vocabulary only would not result in a comparable effect. Pre-training guarantees a more natural copying of the actual child language learning, because children are exposed to novel words embedded to novel sentences.

With the same aim of elaborating how statistics and grammar are co-involved in language acquisition, Peña et al. (2002) carried out a series of experiments, also using the method of artificial language learning. First, they exposed their subjects to an artificial speech stream of an AXC pattern with A predicting C. The subjects could learn to distinguish words from part words because of statistical cues, but did not extract the rule. A modification of the experiment by inserting 25 ms speech breaks to mark word boundaries provoked subjects to abstract rules, maybe, because the artificial stream became more natural-language-like. Again, extending the time of exposure from 10 to 30 minutes did not lead to better rule abstraction capabilities. Yet, when the amount of time of familiarization was reduced to only 2 minutes compared to the before 10 minutes, rule abstraction became the dominant learning strategy. The experiments demonstrate that both statistics and rules are necessary for language learning.

Also Yang (2004) responded to Saffran (1996b) by testing whether statistics predict word boundaries in a computational network setting modeling natural language to a similar extent. Pairwise transitional probabilities of a training data set of 226 178 words in child directed speech consisting of 263,660 syllables taken from CHILDES were chosen. Segmentation results by the network were very bad. Over half of the segmented words did not correspond to real words in the corpus. A possible account for this result could be that most words in the corpus were monosyllabic, and even followed by monosyllabic words in 85% of the times. Yang stresses that as soon as additional knowledge such as for example word stress is made accessible, segmentation results immediately will become more precise. Thus, it is important to compare Peña et al.'s data on artificial tri-syllables with natural language learning. According to Yang, a co-involvement of numerous cues is necessary to learn a language, and statistics alone do not suffice: "The simple UG principles, which are linguistically motivated and developmentally attested, can help SLM by providing specific constraints on its application."(Yang 2004:453).

Bonatti et al. (2005) also hypothesize that both, statistical cues and the extraction of rules for parameter setting play a role in language acquisition. General statistical computations are constrained by linguistic representations, and vice versa. Even though statistics are calculated, phonology as a specific linguistic representation restricts its scope.

Their hypothesis is that one of the linguistic specific innate phonological properties is a “labour” division between consonants (Cs) and vowels (Vs). Though both Cs and Vs are linguistic units of the same category, both are phonemes; they differ with respect to storage and processing. It seems that Cs have a stronger connection with the lexicon, and Vs with prosodic information on a syntactic level (Bonatti et al. 2005). Different considerations lead to this hypothesis. First, Cs universally are far more frequent than Vs within the phoneme inventories, but also prefer to alternate in quality, realized in alternations of manner or place of articulation, whereas Vs often alternate in quantity, as in length, pitch or intensity (Bonatti et al. 2005). What also supports this view is that there are strong restrictions on adjacent consonants within the same roots, namely the OCP effect, especially in non-concatenative languages like Arabic. These restrictions do not occur on vowels. There are many trisyllabic words with identical vowels, as in the Italian words *banana, rotolo, birilli, cenere,* greek *thalasa, irini,* Turkish *kelebek, arkadas.* Similar observations had led formal phonology to the conclusion that Cs and Vs are represented on separate tiers (Goldsmith 1976). Historically, Vs also undergo stronger changes than Cs. Children are already aware of this linguistic property of the language they speak.

Further, prosody phenomena like vowel harmony aid syntactic processing by reducing contrast, which on the other hand is useful for lexical access and mainly realized in Cs, e.g. in consonant disharmony as the OCP effect. These distributions hold for all languages. The size of the C versus V inventory does not matter (Bonatti et al. 2005).

If this distinction between Cs and Vs is correct, Bonatti et al. (2005) argue, humans should only calculate and use statistic information on adjacent Cs. This does not only hold for phonemes that are adjacent in the speech stream, but also adjacent Cs on a from the V-tier separated C-tier. Statistical information about adjacent Vs would be irrelevant for lexical access. Further, if Vs are connected with syntactic processing, statistical information is not appropriate, because for syntactic processing access to stable grammatical rules is required.

Newport and Aslin (2004) in contrast assume that all transitional probabilities among phoneme sequences are calculated and used in processing. A CC sequence will thus be as informative as a CV or VV sequence.

To confirm their hypothesis, Bonatti et al. (2005) ran an experiment, similar to the one by Saffran, Newport, and Aslin (1996a), but presenting two sets of stimuli: one speech stream consisted of nonwords that only by their Cs gave statistical cues for segmentation, while the Vs varied within and across nonwords; and one speech stream where only the transitional probabilities between Vs gave cues for segmentation, while the Cs varied. In the first condition, nonwords could still be identified. In the second condition, the ability to parse the stream was lost. That demonstrates that only Cs carry linguistic information which is easier accessible for listeners who want to segment speech. Only the C-tier seems to deliver information which can be used statistically.

Consequently, in learning phonotactics both, statistics and grammar play a role. Modern OT models of stochastic OT, for example GLA (Gradual Learning Algorithm), can account for gradience in grammar (Boersma & Hayes 2001). This model proposes that rankings are based on statistics. Building blocks of this model are that the candidate is evaluated stochastically, and that the ranking follows a continuous scale. The constraints have numeric ranking values. The higher the value, the higher the constraint is ranked. Sometimes constraint value ranges can overlap. This modification is made to capture variation, and also to account for gradient wellformedness judgments. Another approach by Pater and Coetzee (2005) assumes gradient information to be emerging from the lexicon. Gradience in grammar is accounted for by lexically specific constraints. This approach resembles Pierrehumbert (2003), who also models probabilistic phonotactic effects to be emerging from the lexicon.

Saffran Newport and Aslin however clearly state that statistics alone, but of course various statistical cues support the language learning child. We will get back to this issue in section 4. of this chapter. Before that, I will discuss where phonotactic knowledge is stored.

3. Mental representation of phonotactic knowledge

As discussed, phonotactic restrictions have led formal linguists to the point of view that the syllable is a linguistic unit, which can be compared to phrases in regards of structure and hierarchy. Whether phonotactic knowledge thus is represented in syllables, so if syllables are the underlying mental category for phonotactic knowledge, is unclear. Some researchers claim the syllable to be an indispensable processing unit, but most studies in fact speak against this view. Besides that, there are phonological phenomena such as the OCP effect that take place outside syllabic units and can be accounted for in formal theory. It should also be tried to explain, how this knowledge is mentally represented.

Anyhow it is difficult to yield and provide data that would prove the syllable to be a processing unit, and for things for which the syllable claimed to be important, another explanation always is sufficient: that not syllables but either their constituents or simply bi- or triphone sequences are affecting language processing.

Neural networks sometimes have difficulties to recognize and learn syllables as units (Kochendörfer 2005:124), though other models perfectly implement syllable layer nodes and syllable templates (Gupta & MacWhinney 1997).

Psycholinguistic experiments however hardly support the existence of the syllable as a processing unit. For example, CVC sequences affect better priming than CV sequences, what forces the interpretation that the phonological constituents and not syllabic units trigger the effect (Cholin et al. 2004:49). Further, it has been argued that suprasegmental phenomena as stress or tone are carried on syllables, which makes them essential units, but on the other hand it is not really necessary to postulate the syllable as a whole to be the carrier. To interpret stress and tone, the nucleus, so a syllabic constituent alone suffices. It follows that most of the times the need of the syllable can be substituted via an implementation of its sub-parts.

Nevertheless, some researchers assume that at least highly frequent syllables are mentally represented. This hypothesis gains support by priming experiments in which words that contain high frequent syllables prime better than words with low frequent syllables (Cholin et al. 2004). Word forms stored in the mental lexicon, because even highly frequent syllables do not yield long-term priming effects, cannot trigger the effect. So, possibly a syllabary of high frequent syllables at a sub-lexical level exists, which ease the computation of phonetic properties on the one hand and accelerate lexical access on the other hand. However, single phoneme representations are indispensable, because so far we can be sure that not every syllable is represented in a syllabary, which would substitute a segmental representation (Cholin et al. 2004:49f). Furthermore, at least in Germanic languages, the syllable is not even a very reliable processing constituent, because syllabification is context dependent (Roelofs et al. 2004:657). Languages such as Chinese that disposes of a much smaller syllable inventory and furthermore does not resyllabify (Cholin et al. 2004:59) could be relying on syllables as processing units. Priming experiments yielded effects of syllabic priming even if the tone did not match (Chen et al. 2002 reported in Cholin 2004:58).

What syllabic representation should be favored over representations of its constituents or just simple bi-phone sequences is questionable. We know that around 10% of the speech input in Germanic languages is resyllabified (Roelofs et al. 2004), and that anyhow listeners are not sure about where to parse bi-syllables (Content et al. 2001). Thus, it should be asked, how much information is then indeed carried by structure, and if it really is grammatical knowledge that carries phonotactics, or if it is not emerging from the lexicon or just calculations over linear bi- and tri-phones sequences.

For the early processed phonological information, two sources of knowledge are supposable. Either it emerges from the phonological representations in the mental lexicon, or from sequences of phonemes stored at the sublexical level, near to where phonetic information is kept.

The first theory postulates that effects of phonotactics arise at a lower level of phonological processing. During the process of recognizing words segments and sequences of segments are activated at the sub-lexical level. The statistics over phonotactics aid lexical access (Vitevitch & Luce 1998; 1999).

The second theory poses that phonotactic knowledge emerges from word-storage at the lexical level. Statistics over phonological chunks represented in the mental lexicon influence lexical access (Hulme 1991).

Both explanations are possible and defended in the literature. For example in neural networks: Auer (1992) modeled sequence probabilities as interactions among sequences in the sub-lexical level; whereas McClelland and Elman (1986) did not encode storages of segments or sequence probabilities in the sublexical level, but defined phonotactic knowledge to be represented at the lexical level (both reported in Auer & Luce 2003:167). Also psycholinguistic research has addressed this question and found evidence for both sources of knowledge. This will be discussed in more detail in the following two sections.

3.1. Hypothesis 1: Phonotactics are both lexical and sub-lexical

Vitevitch and Luce (1998; 1999) were the first to show that both levels of representation contain phonotactic knowledge. Vitevitch and colleagues (Vitevitch et al. 1997) primarily carried out wordlike-judgment and repetition tasks using nonwords stimuli composed of phonotactically common or uncommon sound strings. It appeared that nonwords of a high phonotactic probability were judged to be more wordlike, and moreover were responded to faster in the repetition experiment.

In parallel, Luce and Pisoni (1998) conducted spoken word recognition experiments using nonword stimuli, which were manipulated in regards of the number of similar sounding words and their frequency. The results were slower reaction times for nonwords, which had many phonological lexical neighbors. At a first glance, this might be interpreted as a contradiction, because words with many lexical neighbors are generally composed of common phonotactics (Frauenfelder & Schreuder 1992). In fact, the results reveal two different levels of processing of phonotactic information with different variables affecting each level. A dense lexical neighborhood activates a large competing cohort, which slows down the processing time. A high level of phonotactic probability on the other hand will bear supportive on processing. The more probable a sound sequence is, the quicker the phonological unit in the sublexical level can be decoded.

In a joint project, Vitevitch and Luce (1999) conducted a series of experiments putting in issue exactly the question, if phonotactics emerge from both, the sublexical and the lexical level. They used different experimental tasks: the lexical decision task, speeded same-different-task, and the shadowing task. The stimuli were always the same CVC stimuli with either high or low phonotactics plus lexical neighborhood density. They did not try to disentangle phonotactics and lexical neighborhood within the stimuli, noting that words with a high lexical neighborhood in general also have high probabilistic phonotactics. Instead, they used both words and nonwords, and predicted that lexicality would mediate the results.

As they predicted, words of low phonotactic probability and neighborhood density were processed faster than words of high phonotactic probability and neighborhood density. Nonwords of high phonotactic probability and neighborhood density however were processed faster than words of low phonotactic probability and neighborhood density.

They conclude that lexicality and lexical neighborhood effects dominate for words; but probabilistic phonotactics dominate for nonwords, because they do not have a lexical entry. Their results strongly indicate a two-level processing in which phonotactic knowledge appearing from the sublexical level and deductions from the mental lexicon respectively play a role.

What one could criticize is that they did not control for syllable frequency to exclude the option that the syllable and not bi-phones is the underlying category. And they did not level out the effects on nonwords with high phonotactics, but low neighborhood density and vice versa nonwords with low probabilistic phonotactics, but high lexical neighborhood density. They controlled for both, lexical and phonotactic factors, but do not provide us with information, what sort of knowledge is more reliably used in processing.

Vitevitch and Luce's lexical decision task was repeated in an MEG study, and supports the view of two sources for phonotactic knowledge, implying that phonotactics are processed before lexical items are activated (Pylkkänen, Stringfellow, & Marantz 2001). M350 latencies were measures with the intension to bring evidence for automatic spreading activation. Vitevitch and Luce (1999) could not find any effects of probabilistic phonotactics by measuring reaction times in a lexical decision task, neither in words nor nonwords, due to the task-dependent greater lexical activation. Nevertheless, probabilistic phonotactics should affect processing, but simply not be released in reaction times. An MEG study of the M350 might show, what in an ordinary psycholinguistic setting remains hidden. The M350 is a component serving as a predictor of the frequency effect, being sensitive to frequency, repetition, and cloze probability. It is localized in vicinity of auditory cortex in the superior and middle temporal gyri peaking at 300-450ms; slightly earlier than the N400. If the M350 reflects lexical access, the facilitatory effect of high frequency phonotactics should result in decreased M350 latencies.

The lexical decision study by Vitevitch and Luce (1999) was repeated.[8] The reaction times by Vitevitch and Luce were replicated. An ANOVA on the M350 showed an overall facilitation with high probability words having shorter M350

[8] Only the representation of the stimuli was changed: The originally oral CVC stimuli were presented visually to guarantee comparability with prior M350 studies.

latencies than low probability words ($p < 0.005$), and high probability nonwords having shorter M350 latencies than low probability nonwords ($p < 0.05$), a non-significant interaction between lexicality and probability ($p = 0.2$). Words had shorter M350 latencies than nonwords ($p < 0.05$). The results indicate phonotactic processing at an early level. High probability stimuli though often elicited two M350 peaks. A possible interpretation of this result is that the first peak only indicates facilitation by high probabilistic phonotactics, whereas the second peak reveals inhibition by competition, because both, phonotactics and lexical neighborhood density are frequency dependent and should therefore provoke brain activation of the M350.

Even though the title of the article lets assume that this study would bring evidence for the existence of stored phonotactic knowledge aiding processing besides chunks deduced from the lexicon, this is not the case. Again, the evidence provided is only indirect, and therefore weak.

Criticizing that preliminary research did not do so, Bailey and Hahn's study (2001) is the first attempt to disentangle effects of sound sequence typicality in wordlike judgments that emerge from the lexicon, or the sub-lexical level respectively. In two experiments, participants had to decide over the wordlikeness on complex monosyllabic nonwords as e.g. <zinth> or <zint> on a scale from 1-9. To guarantee a precise result, Bailey and Hahn introduce some more fine-grained measures than have been used in previous work. For phonotactic probabilities, they calculated both, bi- and trigram transitional probabilities and positional probabilities for syllabic constituents. Because of the visual character of the first experiment, additionally bi- and trigram orthotactics were calculated.

For lexical neighborhood density, besides the classical measure of counting all words which differ from the probe by substitution, deletion, or addition in one phoneme as a neighbor[9], a more fine-grained measure was introduced, taking phoneme similarity into account and distinguishing between near misses (lexical neighbors with a one phoneme distance) and isolates (lexical neighbors that differ in two phonemes). Also, lower processing costs for deletions and insertions than for substitutions were presumed. Supplementary, for all lexical neighbors, token frequency was measured.

[9] This measure has been successful in previous research which has used CVC stimuli, although might not be sufficient in studies using complex monosyllabic stimuli.

The result was a general preference for near misses over isolates in wordlikeness. Phonotactics and orthotactics by themselves were significant predictors of wordlikeness, and together, transitional sequence probabilities can account for 18% of the results. Orthotactics alone could account for 16%, phonotactics alone for 15%. All three phonotactic measures together predicted 10% of the data, trigrams alone 8%.

For lexical neighborhood, both the classical measures and the improved measure were evaluated. As predicted, the improved measure accounted for 24% compared to only 8% by the classical method. Together with sequence probabilities, the old measure would account for 23%, whereas the improved measure explains 29% in total. Interesting is that very high or very low token frequency both are not good predictors of wordlikeness. Very high token frequency words thus seem not to have strong connections to their phonological neighbors, as medium token frequency words do.

Both, phonotactic probability and lexical neighborhood density are independently of each other significant determinants of wordlikeness. That points at two different sources of processing knowledge.

In a second experiment, the same task with auditory presentation of the stimuli was carried out. The results were similar. Phonotactics and orthotactics together account for 17%, though bi- and trigram orthotactics alone could only account for 3% (2001:580), which shows that orthography does not have a big impact on wordlike judgments of auditorily perceived nonwords. Including the improved lexical neighborhood measure, 31% of the variance could be accounted for. The duration of the experiment, which was 20 minutes in the first and 60 minutes in the second, did not affect the results. To explain the remaining 70% of determinants of wordlikeness that must have influenced judgments in both tasks, Bailey and Hahn (2001:582) tested 18 additional measures, which all did not contribute to a better account of variance (2001:583).

3.2. Hypothesis 2: Phonotactics are lexical only

Supporters of the second theory that phonotactics is lexical knowledge, are mostly researchers that investigate the working memory. Their prior interest are factors that influence short-term memory recall (STM) in order to find out how long-term memory (LTM) representations are created, namely how learning mechanisms can be explained.

In linguistic STM recall, items are hold in a phonological loop (auditory rehearsal). That LTM phonological representations support the short-term memory performance goes back to Hulme (et al. 1991), who discovered that real words are recalled more easily than nonwords or words of a foreign language. This so-called *lexicality effect* is a result of supportive knowledge emerging from the lexicon.

Also probabilistic phonotactics have an effect on STM recall. Gathercole and colleagues for example found out that children and adults recall best all words over non-words, but among the non-words they perform better on high probability phonotactics (Gathercole et al. 1999, Gathercole et al. 2001). Among memory experts, this effect is traced back to *redintegration*. Incomplete phonological traces in the STM are reconstructed (= redintegrated) by the use of phonological representations stored in the LTM. Recall accuracy is lower for non-words than for words, because fewer entries in the LTM can be used for redintegration.

As discussed in the previous section, phonological redintegration and the lexicality effect do not necessarily have to emerge from the same source of knowledge. In some studies it is considered that also phonotactic LTM representations rather than lexical LTM could have provoked their results (e.g. Gathercole et al. 1999, Gathercole et al. 2001, Service & Kohonen 1995), though they favor the theory of lexical neighbors feeding the STM traces as proposed by Hulme and colleagues (Hulme et al. 1991).

Roodenrys and Hinton (2002), who are also studying the working memory, concretely addressed the question of what is more influential on recall, lexical neighborhood density or probabilistic phonotactics, in two serial recall tasks. Their CVC nonwords did not provoke a bi-phone frequency effect when lexical neighborhood density was controlled, but a significant neighborhood density effect, when the neighborhood size was manipulated and bi-phone frequency controlled. This result leads to the conclusion that lexical and not sub-lexical factors influence STM performance.

Further, Roodenrys and a colleague (Nimmo & Roodenrys 2002) were testing the effects of syllable frequency on recall performance. The frequency of occurrence of monosyllabic CVC non-words within polysyllabic real words was calculated to see whether LTM syllable representations influence the phonological STM performance in recall tasks at a sub-lexical level. Overall, the syllable frequency indeed determined the response accuracy. Striking was that errors most commonly affected the VC transition. Looking at these results, phonotactics surely cannot have caused the errors. Restrictions between onset and rime are less strong than between rime and coda. So, recall in this experiment was definitely not supported by phonotactic structure. Their conclusion is that models which implement a syllable layer which receives activation from a syllable template as e.g. the model by Gupta and MacWhinney (1997) cannot be right. So, these researchers completely ban phonological grammar from language processing. Locus of phonological effects on STM retrieval is the mental lexicon; a sub-lexical level for phonotactic or syllable knowledge is not needed at all.

Of course the results of the studies from the researchers defending Hypothesis 1 and those who defend Hypothesis 2 are highly contradictory. In the final section of this chapter I discuss, how this can be explained and what we extract from it.

4. Discussion

In this chapter it was argued that language needs to be divided in two parts: Grammar and lexicon (Pinker 1991, Ullman 2005). Under question was the nature and place of mental representation of phonotactics. Some studies have claimed phonotactic knowledge to be emerging from the lexicon, viewing phonotactics as extractions from lexical neighborhood frequencies. Other studies see phonotactics as belonging to phonological grammar. Very likely is that both phonotactic grammar and knowledge of sound sequences deduced from lexical neighborhood are used in processing. For acquisition, this allows for some interesting predictions. It means that both memory systems should be involved in phonotactic acquisition and processing: Phonotactics as part of phonological grammar should be processed by the PM, and the DM should process chunk information emergent from the lexical neighborhood in the mental lexicon.

For L2 acquisition the prediction follows that an L2 learner will rely much stronger on sequence probability knowledge he can deduce from the lexicon. Only at a very high level of proficiency L1-like phonotactics will be acquired. Basically all studies that have investigated this question and have also given evidence for phonotactic processing at a sub-lexical level so far have been working in L1 environments. The only study that has investigated the role of illegal versus legal clusters in nonnative speech segmentation and indeed found a use of phonotactics even in an L2 is a study that has only used extremely proficient German speakers of English (Weber 2001). Whether the L2 phonotactic knowledge revealed here is of grammatical or lexical origins, was not tested. However, it must be assumed that it is indeed grammatical, because information about illegal clusters cannot be taken from the lexicon. The lexicon only stores positive memorized information.

A major argument by Nimmo and Roodenrys (2002) against a mental representation of syllable structure, a representation of syllabic constituents is that they detect more recall errors in _VC than CV_. Their explanation that listeners put more attention on word onsets, because only via word onset detection the lexical entry can be accessed, accounts perfectly for this result. This knowledge is not new. Already Bagley (1900, as cited in Hay 2000) could show that mispronounced offsets less affected comprehension than mispronounced onsets. Still, at least theoretically syllable parts are organized in a hierarchical structure, as worked out by generative phonologists (e.g. Selkirk 1982). It is hard to see, why this structured organization not should be taken profit from in processing.

If in an experiment stringently only CVC syllables are used as stimuli, this might not occur. In a CVC syllable, every phoneme represents one more or less independent syllabic constituent. Structural effects on processing might be much stronger in C-clusters, which are more restricted in its co-occurrence governed by strict phonotactic constraints. Phonological chunks deduced from the mental lexicon fall short of grammar. We have seen that sound strings are equipped with phonotactic information. If any of this phonotactic information entails grammar, it must emerge from storage at a sub-lexical level, because only here sequential implicit grammatical knowledge can be processed, outside the lexicon. Only in theory, if the lexicon would contain syllabified entries, one could postulate that phonological grammar could come from the lexicon. This is definitely not the case. No language uses syllable structure contrastively.

Previous memory research dealing with phonotactics (Gathercole et al. 1999; 2001; Roodenrys and Hinton 2002; Storkel & Rodgers 2000) mostly worked with bi-phone statistics in simplex syllables. Not every bi-phone carries comparable information. Pertaining to the syllable template, CV or VC bi-phones do not satisfy grammatical information as CC bi-phones, which belong to one and the same syllabic constituent and are much more bound in their co-occurrence. Research also has shown that onset C-clusters are processed as perceptual units just like singletons (e.g. Halle et al. 1998).

This provokes the hypothesis that C-cluster representations are represented sub-lexically. C-clusters can be viewed as phonological units equal to singletons, because they are grammatically bound constituents with constraints that are intrinsically represented outside the lexicon that govern them. The only study that disentangled phonotactic and lexical effects on nonword processing and found a measurable effect by phonotactics besides a lexical effect used complex syllable stimuli (Bailey & Hahn 2001).

I am not arguing that syllables are effective processing units as wholes, but would like to claim that syllabic constituents are important processing units on a grammatical level.

Of course, for lexical activation word onsets are maximally important. If a presented stimulus only contains of CVC, it is traceable why the subject maintains a CV sequence better than VC. The focus on CV promises quicker lexical access. However, one can wonder, what would have happened, if CVC were compared to CCV. I hypothesize that the onset CC in a CCV stimulus would be maintained better than the CV in a CVC stimulus, and respectively a coda CC in VCC would be less affected by errors than a VC in CVC. If that were the case, this would be a perfect argument for grammar, because it would show that phonotactic constraints that govern within syllable constituents are mentally represented.

So far, I provided arguments for mental representation and use of syllabic constituents. However, I even want to go further. I assume that powerful phonotactics sit in the consonants alone. This topic has been brought up by Nespor and colleagues (view section 2.3.), and many more examples can be found that consonants and vowels indeed play different roles in perception and storage. Formal phonology separates Cs and Vs on different tiers (e.g. Goldsmith 1976, McCarthy 1981, Prince 1984). Very prominent examples for this theory are Semitic languages. In these languages, Cs carry the lexical content of the word, and Vs have morphological functions (McCarthy 1981). In contrast, there is no reported language where vowels would form a root. Also in Germanic languages infixation used to be a productive word formation rule; and though it is unproductive nowadays, it is still visible in umlauts. Lexical priming tasks have shown that allomorphic variants like *sane* and *sanity* prime each other very well and not worse than phonologically more transparent pairs like *sane* and *insane.* These results support a model of abstract representations that accept both vowels (Marslen-Wilson et al. 1994 in Marslen-Wilson 1999:112) and even lexical representations that separate Cs and Vs on different tiers. This sort of representation could also account for phonological variation for example in dialects, which mainly affects Vs. Marslen-Wilson is a supporter of a model that functions without phonology and operates with phonetic features and morphemes alone (Marslen-Wilson 1999:111), but according to me that would be too simple. I go for a model that includes a phoneme layer, where Cs and Vs and also C-clusters as they occur in on- and offsets are represented. The phonemes, which mainly send activation to lexical representations, are the consonants. Also vowels activate lexical representations; otherwise it would not be clear how minimal pairs like Dutch *hit* 'pony, nag' and *hut* 'cottage' are processed, but definitely vowels are less prominent in accessing the lexicon. Their function is primarily to encode prosodic information that is used to calculate the syntax.

If we act on the assumption that phonological forms of words are searched in the lexicon, then it appears logical that the human brain will put prior attention to phonological properties, which are most promising to lead to quick lexical access. Experience of language will always lead to the generalization that lexical entries most frequently start with a consonant, and given the fact that language is bound to temporality, Cs most frequently open a cohort[10] in which the correct lexical entry will be searched. In analyzing a speech input, Cs thus play an important role in two cooperative respects: they strongly support a quick activation of the correct word, and at the same time heavily indicate a word or morpheme boundary. Research (e.g. Booij 2002, Hay 2000) has also shown that productive affixes mostly have consonantal onsets. Productive affixes are probably stored independently in the lexicon. V-initial suffixes also exist, but are less likely to become productive. Already independent storage of V-initial suffixes bears some problems, because they provoke syllabification. Moreover, V-initial suffixes hardly create phonotactically illegal transitions. Morphological parsing has been simulated in a simple recurrent network. This was able to parse morphologically complex words if the boundaries are composed of phonotactically illegal junctures. Suffixes starting with a V never got parsed (Hay 2000). So, Cs also contribute its role to word formation, and are an important factor in shaping the lexicon.

Hence I argue that word onsets are of course important, but that primarily Cs and not onsets elicit lexical access. If Cs gain their status because of the overall high frequent presence at word-onsets, or whether this needs to be traced back to C-inherent universal characteristics, as Bonatti et al. (2005) argue, we do not know.

[10] Going back to the Cohort Model (by Marslen-Wilson; described in Marslen-Wilson 1999).

However, Cs strongly seem to have an impact on lexical access, word recognition and segmentation.

A first important notion is that all the reported experiments in section 3., which address the source of phonotactic knowledge, required lexical processing. No matter if it were wordlike-judgment tasks (Bailey & Hahn 2001), lexical decision tasks (Vitevitch & Luce 1998, Pylkkänen, Stringfellow, & Marantz 2002), or serial recall experiments: the subjects must have always concentrated on lexical access, and not on syntactic processing. This might have caused a disregard of vowel processing.

Results by Bailey and Hahn support this hypothesis. In their wordlike–judgment task it appeared that mainly C onsets followed by codas influenced wordlikeness decisions. Vs did not affect the judgments (Bailey & Hahn 2001:584f). Their account is that two vowels which were compared in the judgment task often either were identical or only differed minimally from each other in place of articulation. However, the task requires lexical knowledge, which is here claimed to be connected to Cs and not to Vs. Hence I would expect this outcome.

Other studies also endorse this idea. As mentioned, stress is marked by vowels, for example using vowel length for stress marking. It is known that stress is used for segmenting the speech stream. Speakers of English or Dutch expect word onsets of the stress carrying strong syllables with long vowels or diphthongs as opposed to weak syllables, which contain a schwa-vowel. Is a strong monosyllable word like English *mint* following a weak nonword (e.g. *mintev*), word recognition is faster than when it is preceded by another strong syllable (e.g. *minteiv*) (Cutler & Norris 1988). However, if listeners can choose between relying on stress or a second cue by illegal versus legal consonant clusters, they will disregard stress and use phonotactic information for segmentation (McQueen 1998; Mattys et al. 2005). Similarly, if vowel harmony and illegal versus legal phonotactics respectively give cues to morphological parsing of Finnish compounds, in an eye-tracking study, readers put their attention on Cs (Bertram et al. 2004).

Especially the last examples of illegal phonotactics aiding lexical access show, that not just word onsets aid processing. It is rather a co-involvement of coda and onset Cs across morpheme or word boundaries that provide useful cues for lexical access. V-nuclei cannot compete against Cs. Having called attention to the impact of Cs across morpheme boundaries, which frequently map with syllable boundaries, does not mean that syllabic structure do not contribute to processing.

With this discussion, I aimed at showing that phonotactic grammar does play a role in processing. Prior to lexical access, Cs and Vs on the sub-lexical level are activated, and bi-phone information is evaluated. C-clusters provide more important cues for lexical access: if the bi-phones are violating the phonotactics, they deliver information, which is used for word and morpheme parsing. If the C-cluster forms a unit that belongs into a syllable constituent it delivers strong cues for accessing the correct word entry in the mental lexicon. This again might find support by syllable structure. It would be strange, if the brain would not take profit from the fact that syllable boundaries universally are likely to align with word boundaries. CV transitions rarely provide information about word or morpheme boundaries, and therefore contribute fewer cues to lexical access.

If language processing indeed works that way, it could account for the differences in generative theory that respects the hierarchical structure of syllables and view phonology as a grammatical component, and contradictory results gathered in psycholinguistic experiments. Even long distance relationships between Cs as the before mentioned OCP effect can be accounted for.

5. Summary

This chapter has shown that research about the nature of phonotactics is controversial. If one wants to view phonotactics as a grammatical component stored outside the mental lexicon (e.g. Bonatti et al. 2005; Vitevitch & Luce 1998, 1999), a general psychological reality of grammar needs to be presupposed. Not every linguist supports that theory. Language could also be grounded on associations. Such statistical generalizations would not need grammar. Phonotactics are one of many regular distributional patterns a listener or learner may observe, and they could be abstracted from word-forms stored in the mental lexicon (e.g. Saffran et al. 1996; Nimmo & Roodenrys 2002).

In the discussion, the view of considering phonotactics as grammar was supported. The advantages of taking benefit from syllable structure in processing were pointed out and a special role of consonants in phonotactic processing was suggested.

C. Phonotactics and the lexicon in acquisition and processing

This chapter is about the role of sub-lexical phonotactic grammar in processing and acquisition. The first part describes and discusses the importance of phonotactic grammar in word learning in the L1 and L2 respectively. The second part of the chapter describes a psycholinguistic experimental investigation. The investigation should reveal, if grammatical phonotactic knowledge is involved in native language processing. This experiment was supposed to pave the ground for future research on the correlation of phonotactics and lexical acquisition in L2 learning. 3. summarizes the findings.

1. Phonotactics and lexical acquisition

Language learning is a complex interactive process. Words have to be acquired with their meaning and pronunciation, and syntactic grammar has to be learned. Passive knowledge is necessary in order to understand language, but also active knowledge about the language has to be acquired in order to speak. This includes an understanding about the productivity of grammatical rules.

It is known that the acquisition of one type of linguistic knowledge supports the acquisition of another type of knowledge. The acquisition of meaning supports the acquisition of syntax, and vice versa. The acquisition of phonotactics bootstraps the acquisition of word-forms (e.g. Elsen 1999). The latter is of particular importance for this study and will be discussed in this section.

1.1. Child language development

In the initial state, before we are even able to speak, we still have the option to produce and perceive any phone. Only after a certain amount of L1 exposure, we start categorizing the phonemic input in favor of quickly accessible phonemes in the long-term storage. As soon as categories are set, it becomes very hard to shift them. Already 12 to 14 month olds stop discriminating non-native speech sounds (Jusczyk 1992:24). Also phonotactic language processing in L1 acquisition starts very early. Already 8 to 10 month old infants can distinguish their native language's phonotactics from non-native phonotactics, even before the first words are acquired (Jusczyk 1992:48). This suggests that phonotactics plays an important role in language processing, and it must be hypothesized that without this ability, we could not be able to segment speech and build up a lexicon (Jusczyk 1992:18).

Children's phonological production skills do not develop symmetrically with their perception skills. That children before they start producing complex syllables generally simplify them to CV via deletion (e.g. *spoon* → /su/; /pu/ or *tree* → /ti/;/ri/)[11] (Young-Scholten & Archibald 2000:65) does not mean they do also perceive them in a simplified manner. Still, the production of first C-clusters leads to a vocabulary spurt, which shows that production is important for lexical acquisition (Elsen 1999).

In L1 lexical acquisition, two phases need to be distinguished. Initially, at the age of 10 to 18 months, the child only learns a few words, around 2 or 3 new words per week. All of a sudden, the child starts acquiring many new words, up to 10 per day. This phenomenon has been labeled as vocabulary spurt.

What exactly triggers the vocabulary spurt is not completely clear. What is known is that the child needs the skill of *incidental word learning*. That is the ability of learning new words without instruction by using the strategy of frequent repetition. Via *fast mapping* children already create lexical entries for words they only heard once or twice. These entries contain fragmentary information about the phonological structure as for example number of syllables, stress, and onset; further crude hypotheses about the meaning are stored. The advantage of fast mapping is that with every new occurrence of the word in the input the child can add additional information to specify the lexical entry. These fast mappings are dependent on early re-occurrence in the input to stabilize the activation value (in Rothweiler & Meibauer 1999:20).

Additional linguistic criteria navigate the spurt. Children's knowledge that words refer to things develops in parallel with the vocabulary spurt, and the knowledge to categorize things. Also, the child makes articulatory-phonological improvements in this period, which have a positive impact on novel word learning. Further besides prosodic and phonological criteria the child acquires first syntactic principles, which help to structure the input and produce first complex phrases. Syntactic and phonological improvements lastly play a role in the acquisition of grammatical morphology. All these linguistic factors seem to

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[11] From this data it is assumed that it can be traced back to UG knowledge of how to simplify complex syllables.

interact and influence an improved acquisition of new words (in Rothweiler & Meibauer 1999:17).

1.2. Phonotactics influence lexical acquisition

From prior studies we know that various factors influence vocabulary acquisition, for example word frequency, phonotactic probability and also neighborhood density (Storkel 2004:215).

In this study, we focus on the interplay between phonology and lexicon in acquisition. That an interaction between these two linguistic components exists has been shown in previous studies.

A diary study of child A.'s lexical acquisition (Elsen 1999) shows that the vocabulary spurt is supported by improved articulatory knowledge. Before the age of 1;2, A.'s vocabulary does not contain many words. However, the words that are produced at this early age share certain phonological characteristics. Stress for example is almost only penultimate; unstressed syllables in primary position as *ba.* in German *Banane* are deleted, most syllables have a CV structure, and only few CVC, di-syllables are usually reduplicants, tri-syllables hardly occur. With regards to the phoneme inventory, words with fricatives are either avoided or articulated without fricatives. Three different strategies are used to do so: reduplication as in /nana/ (Nase 'nose'), deletion /du/ (zu 'closed'), or occlusion /data/ (Tasse 'cup'). Elsen discovered that A. for articulatory reasons only did not use and pronounce words, which should have been, because they played an important role in her life, as e.g. Hund ('dog') or Schlüssel ('keys'). Many of these words contained fricatives she was not able to pronounce. When her grandmother offered her a baby talk expression *wauwau* for 'dog', she started using this alternative immediately. For *Schlüssel* another avoidance strategy was used: overextension. After prior attempts to pronounce the word had failed, she used a self created homonym /du/, which also meant *zu* ('closed') in her language. Because of its contextual-semantic close relationship, this homonym seemed adequate to her to use. Until the age of 1;2, many baby talk words and homonym pairs were used. Altogether, the first words shared a reduced phoneme inventory and simple phonotactic patterns, also when the intended words were phonotactically and phonetically more complex.

At the end of 1;2 a sudden non-linear vocabulary spurt started. At the same time, also changes in the phonology took place. Stress was acquired correctly, fricatives occurred, and occlusions, reduplications and other simplification strategies were given up, schwa was acquired, and most interestingly for the underlying study: first consonant clusters were used[12]. As a result, baby talk words and homonyms could be given up.

To express the importance of the acquisition of fricatives for the vocabulary spurt in numbers: the amount of new words containing fricatives was 60-75% (1999:93-95). This shows that phonological acquisition and word acquisition are related. The lexemes itself are not new, the referents are acquired much earlier. To manage the step from baby talk as *wauwau* to the real words as *Hund,* articulatory improvements are urgent. It also affects a give-up of a homonymic overextended use of words as *Hund* 'dog' for 'cat'.

Other phonemes and specific C-clusters however do not show such a clear correlation (ibid:98). Stemberger though has reported a similar observed correlation between plosives and vocabulary spurt (ibid:95).

Still, a correlation between word learning and phonological development in child language acquisition is obvious. In the following section, another correlation will be introduced: the interaction of short-term memory (STM) recall performance and lexical development. Lexical and phonological development and STM performance seem to be three components, which under majestic dependency support each other in language learning.

As already mentioned in chapter B., Children’s performance on serial recall of words and non-words is dependent on phonotactic probability. This has been shown in two studies by Gathercole et al. (1999, 2001). Children recall words better than non-words, and non-words with high probabilistic phonotactics are recalled better than those with low phonotactic probability. Moreover, STM performance on nonwords correlates with the lexicon size.[13]

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[12] The first clusters were among the high frequent consonant bundles offered in the input, as e.g. /br/ ect in onsets and /ns/, /nt/ etc. in codas (personal information by Elsen).

[13] The way Gathercole and colleagues tested this was the following: The materials for their first immediate repetition experiment contained lists of CVC stimuli in 4 conditions: high; low and very low bi-phone probability non-words, and words. In a second experiment, among 102 children, 16 children of each group were chosen that differed maximally in lexicon size.

As expected, words were recalled more accurate than non-words, and nonwords with high probability were recalled more accurate than those with low probabilistic phonotactic patterns. The group with a higher lexicon size showed a better performance in serial recall. However, they did not make a more advanced use of neither lexical nor phonotactic knowledge.

This discovery allows an indirect line of conclusion. It is known that the memory is heavily involved in any sort of learning. If serial recall performance not only correlates with the phonotactic probability of words, but further also with the lexicon size, it can be assumed that phonotactic knowledge might correlate with lexical acquisition. In other words: the capability of accessing phonotactic information is required for building up a sizeable lexicon. Consequently, children with a weaker memory could do less well in relying on lexical and phonotactic cues, and therefore have a smaller lexicon size. LTM of a language's sound structure is important for immediate memory of familiar words and particularly novel words.

The correlation between STM recall performance and phonotactics has further been shown in a study with disordered children (Beckman et al. in press). It compared normal developed to specific language impaired and phonologically disordered children in order to investigate, whether phonotactics supporting lexical acquisition is processed as articulatory phonetic information, or as phonological grammar. Specific Language Impairment (SLI) affects grammar processing, whereas phonological disorder (PD) is related to articulatory phonetic difficulties, for example difficulties in articulating consonants. As phonotactics are to be assumed on a higher phonological grammar level, SLI children should be sensitive to varying phonotactic probabilities in a recall task. If phonotactics are processed together with other articulatory phonetic information, PD children should be affected by varying phonotactic probabilities.

Beckman et al. (in press) compared the three groups of subjects on their recall performance on nonwords with varying phonotactic probability.[14] The result was that both PD and SLI children overall had more problems with this task than normal children. For PD and SLI children respectively vocabulary size was a better predictor on repetition performance than age as for normal children. SLI children however per se have a smaller lexicon, so it is not clear if a direct causal

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Post hoc they controlled, if syllable or single phoneme frequencies triggered the results rather than bi-phone statistics. 83 items never occurred as a syllable in the corpus, 40 items occurred at least once in a CVC sequence within a word. The ones that had a nonzero syllable frequency were recalled better than the ones with zero syllable frequency. Syllable frequency values were equal for high probabilistic non-words and words (Gathercole et al. 1999). In 2001, they compared these results to a serial recognition paradigm, using children and adult subjects.

[14] Stimuli were poly-syllabic nonwords with simple CV structure, taken from Frisch, Large, and Pisoni (2000) and were split into two groups of low versus high probabilistic phonotactics. Repetition performance was analyzed versus age, vocabulary size, and also vocabulary size versus severity of SLI and PD respectively.

relationship between SLI vocabulary size and repetition performance may be drawn, but it may be assumed that small lexicon size, lowered recall performance and grammar difficulties are in cooperative interplay. The best predictor for the phonotactic probability effect in SLI children is the “global measure of grammatical knowledge, including procedural knowledge of inflectional morphology, syntax, and word meanings, as well as the phonological knowledge that supports the lexical expansion” (Munson et al. 2004 in Beckman et al. in press:7). Consequently, this study implies that phonotactics have a grammatical component.

Even at an age where SLI children’s recall performance of real words does not differ from normal developed children anymore, recall on nonwords is significantly impaired. This suggests that SLI children have difficulties in making generalizations about phonotactic characteristics on an episodic grammar level of lexical representations (Beckman et al. in press:7). The reason that SLI children have difficulties acquiring novel words and remain with a small vocabulary is that they lack of the capability to create phonological representations in the first place.

PD children also perform less well on the repetition task, but do not necessarily also have a smaller vocabulary size than normal children of the same age (ibid:12). They simply have lower perceptual skills, but do not perform relatively worse than normal children dependent on phonotactic probabilities of the stimuli. That shows that PD children are not impaired at a level of phonological grammar. Only the lower level, where abstractions over the phonetic space are made, is affected.

SLI children though have the problem to encode “generalizations at a more abstract level of the phonological grammar” (ibid:15). Nonwords are difficult to process when they have an unfamiliar structure. And of course, nonwords always have an unfamiliar structure, also those with high probabilistic phonotactics.

So, also this study supports the hypothesis of a relation between phonological grammar and lexical acquisition. In order to acquire a lexicon, humans need “robustly abstracted coarse-grained phonological representations to efficiently parse unfamiliar patterns such as novel phone sequences.” (ibid:7). Phonotactics work on a different than the articulatory level.

Storkel and Rodgers used a more direct measure of investigating the relationship between phonotactic probability and lexical acquisition (together in 2000; and Storkel 2001). They tested how 3 to 13 year old children would learn nonwords of varying phonotactic probability, which were leveled in regards of positional segment, and bi-phone frequency. The nonwords were matched with a picture and presented auditorily and visually in a classroom session. The subjects first were trained on the nonwords, and after a break, their recognition was tested: they were exposed to the words again and had to decide whether they had heard them before or not.

This method again demonstrated that high probability phonotactic nonwords were memorized better than low probability phonotactic nonwords.[15] Even at a stage when children are still developing phonological productivity, they already make use of phonotactic distributions to take them as support for vocabulary acquisition: "A language subsystem needs not to be adult-like to play a role in lexical acquisition", (Storkel 2001:1331).

Regrettably, Storkel and Rodgers did not disentangle whether the effect can really be traced back to sub-lexical knowledge. The stimuli they had borrowed from Jusczyk, Luce, and Charles-Luce's (1994) CVC nonwords, had afore been used in Vitevitch and Luce's studies (1998; 1999), who assigned the stimuli a stronger impact by phonotactic probability than lexical neighborhood, because processing times were quickened. Hence Storkel and Rodgers interpret the effect as provoked by phonotactics rather than lexical neighborhood. This might only partly be true. Phonotactics surely will contribute their part to novel word learning, but the growing lexicon might provide good cues itself. That could also explain why children even increase the use of phonotactic frequency with age. Via fast mapping already after one single presentation of a stimulus fragmental representations are created. It could be that only for these first fragmental entries phonotactics are really relevant, and with manifestation of the storage after the initial acquisition already the lexicality effect takes place. As soon as the newly acquired nonwords have established representations in the mental lexicon, they might get connected with similar sounding words, which gives them all more activation weight. Storkel argues this could also "reinforce the phonotactics" (Storkel 2001:1332), which is a convincing hypothesis, too. She did not take into

[15] The 7 year olds yet did not show this effect. This result would be surprising; age and phonotactics should not interact, because already infants have developed the sensitivity for phonotactics. A later correlation showed that 7 year-olds did better on memorizing non-words containing "late" acquired phonemes. Even though they could produce all the phonemes correctly, they seem to have put their attention on the more difficult ones. These findings lead them to the conclusion that in early child lexical acquisition singleton phonemes might be more influential than b-phones. However, Storkel's follow-up study (2001) with 3-7-year olds excluding "late acquired phonemes" as a factor revealed that at any age nonwords with high frequent phonotactics are memorized more easily.

account that with the repeated presentation of the stimuli in the longitudinal training session she might have confounded the effect. Only in a later study of a child language acquisition corpus she emphazises that neighborhood had a strong influence on the age of acquisition especially with infrequent words of a short length. “The organization of existing lexical representations influences the creation and integration of new representations. In particular, similarity to many existing lexical representations facilitates lexical acquisition.” (Storkel 2004:215).

To what extent phonotactics play a role in second language acquisition, has so far only been tested in two studies by Service and Craig (1993) and Service and Kohonen (1995). These researchers hypothesized that if a learner has the talent to build up and use phonological representations, which is a fundamental competence in recall tasks, he or she will be much more talented to learn an L2. The phonological STM thus plays a big role in second language acquisition. In order to memorize words, to be able to create entries for phonological forms in the mental lexicon, these items need to pass the short-term memory. Ergo, the better the STM works, the better a language can be learned.

The first study (Service & Craig 1993) on the connection between repetition behavior and non-native language learning tested English native subjects on their repetition performance on English words and English sounding non-words, and Finnish words and Finnish sounding non-words. These subjects performed better in memorizing English sounding non-words than Finnish words. The result indicates a transfer from the L1 phonotactic distributions and the L1 lexicon.

In a follow-up study, Service and Kohonen (1995) investigated the correlation between repetition accuracy of English-sounding non-words and school report grades in English as a foreign language. Their finding is that both are dependent factors on foreign language learning capacity. Good reading and listening skills provide for a greater availability of comprehensible input. The capacity of the phonological STM seems to directly correlate with foreign vocabulary learning. The general vocabulary size further affects other aspects of foreign language acquisition.[16]

[16] The experiment was a longitudinal study of 42 Finnish primary school pupils, who they investigated over the period of 4 years 4 times in a repetition task. When the experiment started, these pupils had no knowledge of English. The stimuli they used were English-sounding di- and four-syllabic nonwords, which consisted of syllables that were taken from multisyllabic words whose syllables were exchanged and therefore even contained real morphemes. Examples are mindon, geplore, landipation, subdegerent (1995:159).

In the experiment, the children had to repeat both Finnish real words and the English non-words. In order to investigate the correlations of foreign nonword recall and school achievements, they calculated a mean of all grades, and added three extensive measures of language proficiency, The results revealed an interaction between recall performance and the language proficiency tests, thus an interaction of phonological STM, language learning and vocabulary knowledge. Any task that tested for vocabulary size could be correlated to performance in the recall task. Other skills like written production and reproduction of phrases or grammatical understanding though are not interconnected with the functions of the phonological STM.

To summarize, the core findings are that grammatical understanding is less dependent on phonological representations than vocabulary knowledge, but that the ability to create phonological representations in the mental lexicon a priori requires a well-functioning STM. The repetition skills reflect the ability of building up a lexicon. These correlations remained significant over time.

The results correlate with the before mentioned studies on the relationship between STM recall, lexical acquisition and phonotactics (Gathercole et al. 1999; Gathercole et al. 2001; Storkel & Rodgers 2000; Storkel 2001; Beckman et al. in press).

1.3. Discussion

The correlation between lexical learning and phonology in first language acquisition has been demonstrated in studies using various methods (e.g. Storkel and Rodgers 2000, Gathercole et al. 1999). In order to acquire a second language vocabulary, theoretically phonotactic knowledge should also to be attained. The results of a repetition experiment (Service & Kohonen 1995) suggest that this in general is the case.

In chapter B, I discussed that already for native language processing the researchers do not agree whether phonotactics are fully deducible from stored items in the mental lexicon (e.g. Hulme 1991; Pierrehumbert 2003), or whether there is a sub-lexical involvement in phonotactic processing which would account for the grammatical component of phonotactics (e.g. Vitevitch & Luce 1998, 1999). Phonotactics can thus be either lexical alone, or both lexical and sub-lexical. The studies, which have related phonotactics and lexical acquisition, do not clearly state whether the detected effects of probabilistic phonotactics on word learning and lexicon size are to trace back to sub-lexical or lexical information alone.

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testing communicative skills, including a vocabulary test, further a traditional grammar based test, and lastly a measure of the English vocabulary size.

Nothing is known about whether L2 phonotactic knowledge is grammatical or lexical, or both, and to what extend. Even if we assume that in L1 lexical acquisition sub-lexical phonotactics aid novel word learning; this might not be the case in an L2 learning condition.

If L2 learners indeed have difficulties with acquiring procedural knowledge as claimed in Ullman (2005), it will not be easy for them to develop a reliable phonological grammar in the first place, and almost impossible to take profit from grammatical phonotactics for lexical learning. If phonotactic knowledge that aids lexical acquisition is anyway only deduced from the lexicon, these problems should not occur.[17]

The study by Service and Kohonen almost allows for an indirect conclusion. They report no correlation between recall performance and proficiency in the L2 grammar (1995). However, that does not exclude the possibility that L2 phonotactics base on grammar, because L2 grammar much bases on declarative knowledge (Ullman 2005).

What always needs to be kept in mind when talking about L2 acquisition is the transfer from the L1 to L2. In L1 acquisition, it seems quite obvious that the mental lexicon in its initial state is empty. Children thus use the strategy of relying on knowledge of phonotactic patterns for creating phonological representations. The more likely a sound-sequence is, the quicker a child will memorize the word that contains it (Storkel & Rogers 2000; Storkel 2001). L2 learners however are not a tabula rasa. It is known that L2 learners for example shift their L1 semantic categories, and it is very difficult to acquire new semantic category boundaries. They also transfer their phoneme categories, and have similar problems shifting the boundaries. Also phonological entries of the mental lexicon are transferred.

Concerning the L2 lexicon, two theories are logically plausible. In the initial state, an L2 learner does not have an L2 lexicon. The first option is that the L2 learner transfers his L1 lexicon. Initially, he could rely on information about L1 lexical neighbors to create new entries in his L2 lexicon. Adding new L2 phonological representations to the phonological storage pool, probabilities of sequences would shift in both, L1 and L2. L2 learners would circumnavigate the problem of acquiring sub-lexical phonotactics. From the start they would deduce L2 phonotactics from the transferred L1 lexicon, which would grow into an L2

[17] Still one thing has to be kept in mind: Ullman (2005) describes phonology as a sort of interface between procedural and declarative information. This might be inherent to the nature of phonotactics being partly lexical and partly sub-lexical.

lexicon. Wrong predictions about sound patterns would be made, which would be corrected and shifted with more exposure to the L2. However, this option could not explain, how the L2 learner could acquire and processes sound sequences that are illegal in the L1, and consequently cannot be deduced from the lexicon, where only positive information is stored. It is not known if L2 learners are able to acquire this information (Weber 2001), but if so, a sub-lexical activity with re-ranking constraints is necessary.

The second option, which would account for the latter question, is to assume no L1 lexicon transfer. In the initial state, the L2 lexicon would be empty. New words will have to pass a phonological filter located behind a sublexical level. Sub-lexical constraints and the phonological filter would be transferred from the L1. Learning an L2, the phonotactic constraints, which are represented sub-lexically, could be re-ranked. This hypothesis requests that universal constraints that are not active in the L1 can be revived. It would postulate UG and L1 transfer. Assuming a stronger impact of the sublexical level at least in the initial phase of L2 learning has the advantage of having an account for how new sound-sequences pass the phonological filter and arrive in the lexicon.

It will be interesting to test L2 learners' recall performance on nonwords containing C-clusters. As discussed in B.4., C-clusters are governed by strict phonotactic constraints. A STM task involving performance on those C-clusters can possibly reveal, whether sub-lexical phonotactics are learned in an L2 and aid lexical acquisition.

However, no matter if L2 phonotactics are grammatical or not; theoretically knowledge of C-clusters should support lexical acquisition. C-clusters carry lexical content, as argued in B.4. If a C-cluster is familiar from the L1 or easy to acquire, this should be a big support for lexical acquisition. However, if the specific C-cluster is nonexistent in the L1, it first has to be acquired. For its acquisition, phonotactic grammar might be necessary and lexical information insufficient. Until it is acquired, it will not be perceived correctly and the acquisition of the lexical item will cause a problem. The creation of a lexical entry will happen, but will be incorrect. The complex L2 lexicon entries will not map with the real forms of the language, and L2 processing, also L2 speech segmentation in consequence will be disturbed.

L2 learners however can become very proficient, dependent on talents and amount of exposure. Thus, there must be learning strategies to acquire a) phonotactics, and b) the lexicon, and it is very likely that the development is parallel in nature, as has been demonstrated in children L2 acquisition (Service & Kohonen 1995) and adult L2 acquisition (Weber 2001). That shows that information about L2 phonotactic distributions can be learned. It could however be that L2 learners try to receive this information from the lexicon. Most researchers that work on the dependency of lexical development and phonotactics see that phonotactic LTM representations could also be stored sub-lexically, but favor models that propose lexical LTM representations only (e.g. Gathercole et al. 1999). An infant or an adult L2 learner though cannot rely as much on lexical information. A learner's lexicon is basically not as defined and substantial yet. Consequently, fewer lexical neighbors can aid acquisition and perception. An additional problem is, if words with for example complex C-clusters are stored incorrectly.

What needs to be asked is why we should assume that it is phonotactic grammar that helps building up a lexicon. It could be the case that sub-lexical phonotactic knowledge is only used for speech segmentation, whereas lexical neighbors, in both L1 and L2, aid lexical acquisition.

What supports the hypothesis of sub-lexical involvement is the following: Novel words no matter if in an L1 or L2 in the initial state are not much different from nonwords. The study by Vitevitch and Luce (1998; 1999) on words and nonwords shows that lexicality and lexical neighborhood effects dominate for words; but probabilistic phonotactics dominate for nonwords.[18] Because nonwords do not have a lexical entry, the listener cannot profit from the lexicality effect. However, nonwords also have lexical neighbors. Processing still is dominated by probabilistic phonotactics. If a new word is given in the input, it activates both the lexical and sub-lexical level. That no match in the lexical level is found immediately initializes the process of developing a new lexical node. For this initial process phonotactics should play a big role. It is even likely that the creation of new entries will be faster if the neighborhood density is low. Low-density words can be acquired faster, because the identification of the absence is finished faster. Phonotactics at the sub-lexical level overtake the lexical acquisition process and are used to create a lexical entry. Entries for phonotactically high probabilistic words will be established more accurately and faster, because their sequence is more predictable. This should be the case in L1 and L2 acquisition. Phonotactic knowledge thus has to be acquired to support L2

[18] Gathercole et al. (1999) yield the same result, though without having guaranteed that the phonotactic effect really is sub-lexical.

vocabulary acquisition. The L2 learner might not improve the L2 without improving the L2 phonotactics. The sub-lexical level can be hypothesized to be more important than the lexical level for novel word learning, because it delivers substantial information for the creation of the mental entry. Difficulties in acquiring a new language might result from the incapability of acquiring L2 phonotactic grammar.

It is known that L2 learners have difficulties in learning new C-clusters, especially if their L1 disallows C-clusters. Tarone (1987) has tested Cantonese, Korean and Portugese speakers' English and found out that these epenthesize by rule according to their L1 phonological grammar. Broselow (1983) reports that Iraqui Arabic learners of English epenthesize word-initially, whereas Egyptian Arabic learners epenthesize between two initial consonants. Anderson (1987) detects deletion in Chinese speakers' English. So does Davidson (1997), with Turkish, Japanese and Chinese speakers. Hancin-Bhatt & Bhatt (1997) finds restrictions to epentheses in onsets, and deletions in codas (This overview is collected from Davidson (2003), and Young-Scholten & Archibald (2000)).

Further studies on English speaker's production of Polish word-initial c-clusters (Davidson et al. 2004), on English speakers' production an perception of Russian word-initial c-clusters (Haunz 2002) and on English speakers' production of Czech legal onsets (Davidson 2003) demonstrated that also speakers, who know complex syllable structures from their L1, use the same repair strategies, if they are asked to perform on more complex structures.

Very little is known about L2 consonant cluster perception. If L2 learners are not able to produce a complex cluster correctly, it does not imply that they are neither able to perceive them as they are. Epenthesis and deletion as described above could be accounted for with articulatory difficulties. According to the SLM, accurate perception is required for accurate production, especially in the initial state of L2 learning, even though perhaps in general production and perception are not connected and independent apparati (Flege 1987). That phonological production must be separated from the perceptual apparatus can be read from several experiments. However, accurate production is not necessarily dependent from its perception. What is known is that Japanese speakers can be trained in producing the English /l/-/r/-contrast correctly, in perceiving them however they will still have problems (Bradlow et al. 1997).

About L2 cluster perception different assumptions can be made. First, they could sound foreign to the L2 listener, but would be perceived correctly. Second, they could be perceived simplified, with epenthesis or deletion, respectively. Dupoux and his colleagues conducted a study that supports this hypothesis (1999). In their experiment, Japanese speakers could not distinguish perceptually between non-words like *ebzo*, which contains with /bz/ a Japanese illegal c-cluster, and *ebuzo*, which a vowel-insertion. According to this finding, production mirrors the perceptual reality.

Third, the non-native-like clusters could also be categorically assimilated to similar native clusters. Halle et al. (1998) conducted several on- and off-line experiments that showed that illegal but pronounceable consonant clusters /tl/ and /dl/ were perceptually assimilated to /kl/ and /gl/. In the on-line experiment the effect was even the strongest. In a gating experiment they showed, that the cluster initial plosive was perceived correctly, when the liquid was absent. The shift to velar perception started in the moment, when /l/ faded in. Due to this result not only phonemes (Flege 1987), but also phoneme sequences are perceptually assimilated. The Perceptual Assimilation Model (PAM) states that not only phonetic differences, but also phonological differences cause troubles discriminating an L2 sound correctly. Not only the phonetic characteristics of a sound, but also the way of how it is embedded between sounds mislead the L2 learners perception (Best 1999).

From these very few studies, one striking observation can be made: There are two types of non-native clusters. Some are illegal *by rule*, so for example violating the sonority sequencing constraint. Others are illegal *by accident*: they are possible pronounceable clusters that just do not occur. Dupoux et al. had tested clusters, which for Japanese speakers were illegal by rule: Japanese does not allow obstruent codas or complex onsets. Halle et al. instead tested clusters, which were illegal by accident. It is very likely that C-clusters that are illegal by accident are easier to acquire than those, which are illegal by rule, because they do not require a strong modification of the existing grammar.

If C-cluster processing is strongly determined by knowledge represented at a sub-lexical level, and L2 learner have difficulties acquiring C-clusters, this could result from the fact that L2 learners have difficulties in acquiring phonological grammar as being part of the procedural memory. If this were the case, this could be modeled in OT. Phonotactic knowledge would be represented outside the mental lexicon in a set of hierarchically ranked constraints. The learner would start out from the L1 ranking learning the L2. During the development of the learning process, L1 constraints would get re-ranked, trying to come closer to the L2 ranking. The ranking of constraints can only take place at the sub-lexical level, because OT is grammar. The constraints would be responsible for delivering cues to find plausible candidates in the mental lexicon. With OT constraints it could also be modeled that C-clusters which are illegal by rule are harder to acquire than those that are illegal by accident, because for the acquisition of clusters illegal by accident not as strong re-rankings will be required.

To find out if this hypothesis can be corroborated, it is useful to investigate L2 speakers of Dutch with the varying L1 backgrounds Russian, Farsi, Modern Hebrew and Japanese. To work with C-cluster stimuli will allow different predictions about how they are acquired by the different groups.

However, these are issues that I will work on in my PhD thesis. First it needs to be found out, if complex syllables involve more phonotactic processing than simplex syllables in the L1. Secondly, it was necessary to consider which task would be appropriate to test the correlation between sub-lexical phonotactic probabilities and lexical neighborhood density, syllable structure and its impact on lexical acquisition. Further a task needed to be designed that would allow for comparing L1 native speakers of Dutch with L2 learners of Russian, Japanese, Modern Hebrew and Farsi.

2. Experiment: A serial recognition task

As preparatory work for my future research, I conducted an experiment with adult native speakers of Dutch to a) get insight into the effects of C-cluster probabilities on nonword recall (2.1.) and b) to find out which task would be appropriate to test this on L2 learners (2.2.).

2.1. Hypothesis and predictions

It is hypothesized that besides lexical neighborhood density also probabilistic phonotactics play an important role in lexical acquisition and language processing (Beckman et al. in press, Vitevitch & Luce 1998, 1999). Earlier studies that make claims about lexical neighborhood effects being stronger than effects from sub-lexical phonotactics usually tested their theories on simplex syllables (e.g. Roodenrys & Hinton 2002). CV and CV relations respectively are however not as phonotactically restricted as CC sequences. Thus, my prediction was that nonword stimuli of high versus low probabilistic phonotactics might not reveal in processing of CVC stimuli, but that they might show up in stimuli with complex syllable structure. Of course, neighborhood density is positively correlated with phonotactic probability, but it is negatively correlated with word length (Storkel 2004:215). This possibly explains the results of previous studies that attributed to lexical neighborhood frequencies a stronger effect on processing compared to phonotactic frequencies. CVC nonwords, because they are nonwords, have a frequency of zero. Here, because CVC words are very short, large neighborhoods are very effective in supporting processing. If words are longer, they are also phonotactically more complex. If grammatical phonotactic information is accessible for processing, the lexical neighborhood loses its efficiency.

To test whether this hypothesis would hold, an experiment was planned and conducted, that would compare performance on high versus low phonotactic probability nonwords of simplex versus complex syllable templates. The prediction was that with increasing complexity of the syllable structure the performance on high versus low bi-phone probability nonwords would differ more significantly. The assumption that guided this prediction with respect to the syllable template is that the processing of C-clusters involves phonotactic knowledge to a much larger extent than CV or VC sequences. This is, because they are phonotactically much more dependent on each other. It is predicted that bi-phones inside complex syllable structures, which are phonotactically more restricted by constraints that govern inside the syllable, in contrast to simplex syllable structures will provoke sub-lexical phonotactic processing.

2.2. Design

The main goal of the considerations described in this chapter were to find an appropriate task for testing how Dutch learning speakers of Russian, Farsi, Japanese, and Modern Hebrew are influenced by phonotactics in vocabulary learning, and how this learning process develops.

To find out which role phonotactics play in lexical acquisition, it is an appropriate method to test the STM performance, as has been shown in previous studies (e.g. Gathercole et al. 1999; Service and Kohonen 1995). STM and LTM functions are related. To create a new lexical entry in the LTM, it is required to hold the new lexical item in STM; otherwise it will not reach long-term storage. To investigate, which role gradient phonotactics play in lexical acquisition, it is possible to offer stimuli of low and high phonotactic probability, as has been done previously (ibid.).

These earlier studies always used serial recall production tasks. However, to test non-native speakers' perception it should always be preferred to use a task that does not involve production. Production data can falsify the results, because it does not only express how a stimulus is recalled, but also which articulatory problems the probands have in their L2.

A method to avoid production would be to ask the subjects to write down the recalled stimuli (e.g. Halle et al.). Besides the fact that this would give the study an off-line character, this is not an option, because orthographic knowledge is an important supporting factor on processing phonotactics. However, I am specifically interested, how phonotactics can be acquired in pure auditory perception. So, an influence by activated orthographic knowledge needs to be ruled out. Choosing to work with Russian, Japanese, Farsi and Modern Hebrew as L1 background languages has the advantage that influences from orthography can partly be ruled out, due to the different alphabet systems being used. Still it must not be neglected that adults mostly learn their L2 from textbooks, repeating written lists of vocabulary. This supports L2 perception (pointed out e.g. in Archibald & Young-Scholten 2000).

A good auditory perception task, which even tests lexical knowledge, is the lexical decision task. However, for the purpose of this study this method is not applicable. For low proficient learners it would be too difficult, and for those who do not know Dutch it would be impossible. Also wordlikeness ratings of nonwords can test the listener's perception, but besides that it should be preferred to use a task that allows comparisons with prior studies, this task only allows insights about the general phonotactic knowledge in an L2, and does not allow drawing conclusions on lexical acquisition. A same argument abandons the speeded nonword same different task, as used by Vitevitch and Luce (1999) as an option.

An artificial word learning task, as it has been used by Storkel (2001) on the one hand has the advantage of directly testing lexical acquisition. On the other hand it is hard to disentangle whether the effects of manipulated phonotactics really reflect the impact of phonotactic knowledge at the sub-lexical level. Also L2 learners make use of fast-mapping (Rohde & Tiefenthal 2000). That could have the effect that already after a first exposure to a new lexical item the subjects would create coarse lexical entries. Later recall could thus strongly be influenced by lexical information.

The best method to study the STM performance of L2 learners therefore is a serial recognition task. O'Brien et al (in press) for example conducted a serial recognition task with native speakers of English learning Spanish with the intention of finding correlations between phonological memory and L2 vocabulary use, besides other correlations like grammatical and narrative skills. Besides of abandoning influences from articulation, they describe the serial recognition task as to be preferred, because "the serial nonword recognition is less susceptible to long-term memory effects, such as lexicality (Gathercole et al. 2001), syllable frequency (Nimmo & Roodenrys 2002), and phonotactic knowledge (Gathercole et al.1999)".

Gathercole et al. (2001) also carried out a serial recognition task and compared the results with those yielded in a serial recall production task, investigating the lexicality effect and phonological similarity effect on word recall. They found that the lexicality effect in the recognition task was much lower than in the production task, which might be due to the concentration on order memory in the recognition task compared to a concentration on order and item memory respectively in the production task. Phonological similarity however had comparable effects in both tasks. That the lexicality effect is abandoned in serial recognition, they interpret as sign that only the phonological memory is asked in this task. They go further to claim that the lexicality effect might base on semantic effects (Gathercole et al. 2001:25). Unfortunately they were not comparing phonotactic probability effects, so it is not completely sure, whether with the serial recognition task phonotactic effects can be tested. Some modifications in the experimental design had to be made. Gathercole and colleagues had confronted subjects with lists of varying lengths between 2 and 6 items. After a short pause, they heard the same stimuli again, either in the same or different order. A problem of this task, which they pointed out themselves, is that this mainly tests the order memory. The subject does not necessarily have to recall each single phonological segment that is contained in the stimuli.

The Sternberg paradigm seemed to be a better task for the purpose here. That is to present a list of 4 stimuli and, after a short break, a probe (Sternberg 1966). The subject's task is to decide whether the probe was in the list or not. The offered stimuli should be nonwords. Nonwords do not have a lexical entry and can therefore simulate best which criteria play a role in acquisition. Besides that, all L2 learners have the chance to perform equally well on them. Real words can be known by one, but not by the other L2 learner, which would yield inconsistent results. With this task, two dependent variables give information about processing: Reaction times (RTs) and error-rates.

However, L2 speakers of Dutch were not tested in this experiment. Former studies have shown that probabilistic phonotactics do not only affect the language learning population. They also play a role in adult native language processing (Vitevitch & Luce 1999, Frisch, Large, Pisoni 2000, Bailey & Hahn 2001). So, first the stated predictions about C-clusters in processing should be confirmed in a study using native speakers only.

2.3. Method

Subjects:

The 25 subjects were students from the Utrecht Institute of Linguistics' subject's pool. They were all native speakers of Dutch. No hearing disorders were reported. They were paid for participation.

Stimulus materials:

The stimuli were monosyllabic Dutch appearing pronounceable non-words. 4 types of syllabic patterns were included: CVC, CVCC, CCVC, and CCVCC stimuli. So, 2 complex onset situations, 2 complex coda situations, 2 simplex onset situations, and 2 simplex coda situations were available for the analysis.

The target stimuli were composed of either only high or only low frequent bi-phones. Bi-phone frequency data calculations were based on 8305 word type frequency information generated from *CELEX lexical database* and the *Corpus Gesproken Nederlands (CGN)*. The *CGN* biphone list was created using 986,793 word tokens.[19] First, high and low frequency values were evaluated for all possible Dutch bi-phones. The list was divided in three parts. The medium part

[19] Bi-phone probabilities could have also been based on type frequencies as it has been the preferred by for example Hay, Pierrehumbert & Beckman (in press:4). However, the frequency of words within the lexical neighborhood has been discovered to be a factor (Bailey & Hahn 2001:579) In any case, the two measures are highly correlated.

was taken out. The bi-phones which occurred in the lower part were summed as the group of bi-phones with low frequency, and the upper part as the group of high frequent bi-phones. All bi-phone frequencies were higher than 0. The frequency ranges for each group are summarized in the table below:

bi-phone	frequency ranges low		frequency ranges high	
	CELEX	**CGN**	**CELEX**	**CNG**
CC onset	30 - 2305	11 - 90	2901 - 27364	16 – 499
CV	6 - 2138	3 - 92	4075 – 38005	11 - 204
VC	2 - 1347	1 - 96	1868 - 43266	19 – 238
CC coda	130 - 1900	5 - 63	2130 - 27367	20 - 499

Table 1: Ranges of bi-phone frequency for all existing bi-phones high versus low.

The CELEX frequency ranges for the bi-phones that composed the target stimuli are summarized in Table 2.

bi-phone	**frequencies from CELEX low**	**frequencies from CELEX high**
CC onset	30 – 2305	2901 – 27364
CV	6 - 2024	4075 – 30096
VC	2 – 1347	3012 – 43266
CC coda	130 - 1900	2130 – 27364

Table 2: Ranges of bi-phone frequency for bi-phones in target stimuli.

To rule out effects emerging from the lexicon, the targets were controlled for lexical neighborhood density, using a log combining type and token frequency.[20]

[20] Originally, I wanted to test stimuli that were arranged in four conditions:

1. High probabilistic phonotactics and high lexical neighborhood density
2. High probabilistic phonotactics and low lexical neighborhood density
3. Low probabilistic phonotactics and high lexical neighborhood density

The log probability of the targets ranged between 1.763 and 2.399. A lexical neighbor was defined as differing from the target nonword through the addition, deletion, or substitution of a single phoneme.

To prevent unknown factors from influencing recall performance and to provide consistency between items, the targets were created in such a way that they would only differ minimally from each other, as for example the low bi-phone probability nonwords /lum/, /lump/, and /xlump/ or /vo:k/ and /vo:kt/ with a high probability. With this, interferences with singleton frequency effects could be minimized. This is important, because single phoneme probabilities could account for a part of the wordlike judgments (8%) in Bailey and Hahn’s (2001) study. Also Storkel and Rodgers (2000) report effects of singletons in their artificial word acquisition study. Words containing late acquired phonemes are memorized better than others. In a study of L2 learners this might also become an influential factor. Therefore it was important to keep the target stimuli similar to allow for comparisons.

Word length has an effect on recall performance, thus it would have been good to control whether all words of the same class were pronounced with constant duration. Due to time limits in the frame of this MA thesis this was not done for this experiment. That word length in terms of syllable complexity will yield different performances, is expected, but does not matter to this study. It is not of interest here to make direct comparisons of reactions on items of different syllable structure within one group of phonotactic probability.

Since the task is auditory, it was not controlled for orthographic bi-gram frequencies. Bailey and Hahn had shown that bi- and trigram orthotactics only minimally influence the results, if stimuli are presented auditorily (2001:580).

A full list of the target stimuli is attached in the appendix.

For each condition 23 test items were included in the task. The tested items were embedded in lists containing 4 items each, surrounded by monosyllabic nonword fillers. The fillers were also constructed in the 4 types of syllabic patterns. The stimulus lists were designed in such a way that every syllable template occurred

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4. Low probabilistic phonotactics and low lexical neighborhood density

To create these patterns was impossible, because CVC nonwords with low phonotactic bi-phone probabilities, but a high lexical neighborhood density on a scale that it still would have been comparable with more complex syllables, do not exist.

only once, to guarantee diversity and avoid confusability. So, the series they were exposed to were as follows:

CVC filler, CCVC filler, CCVCC target, CVCC filler → CCVCC target → yes/no?

Altogether, the experiment consisted of 184 target lists, which requested a yes-answer. 184 filler-lists, in which the fifth stimulus did not match with one of the prior four fillers, were inserted. All lists and all items within the lists were newly randomized for every subject. In total, each subject was exposed to 1472 fillers plus two times 184 targets, which sums up to 1840 nonwords.

Procedure:

Stimuli were recorded at 32,000 Hz spoken by a Dutch native speaker with clear voice and background knowledge in phonetics or phonology. Subjects were investigated individually in a soundproof room. They received the stimuli via headphones. Stimuli lists were presented with 700 ms interval breaks and 1400 ms between the list and the probe. Yes/No-decisions had to be made on a button-box. Errors were counted and reaction times measured from the onset of the probe. Decisions that took longer than 3000 ms were interrupted and counted as errors. The experiment took 90 minutes. Three breaks were included. There were two practice trials before the experiment started.

2.4. Results and discussion

Results:

Reaction times: The RT means measured from the onset of the target probe revealed that as expected the differences in RTs became bigger, the more grammatical phonotactics, the more C-clusters were involved. Among CCVCC nonwords, in which indeed most phonotactic grammar sits inside the structure, the difference was 103 ms between high and low probabilistic phonotactics nonwords. This difference was with 96 ms already smaller for CCVC nonwords, and again smaller for CVCC nonwords. CVC targets with low phonotactic probability were even reacted to faster than to those of high phonotactic probability.

Template	RT for “high”	RT for “low”	Difference
CVC	1143.925	1134.234	-9
CVCC	1145.131	1204.531	59
CCVC	1117.383	1213.361	96
CCVCC	1160.449	1263.010	103

Table1: RT means for each category

Error Rates: 7.2% of all trials among the 25 subjects on all 184 target lists, what sums up to 4600 trials in total, were incorrect. As the RT means, these error-rates were distributed in the expected pattern. Among the CVC nonwords, the error rate did not differ between high and low probability items: CVC nonwords with high phonotactic probability triggered 39 errors and those with low phonotactic probability only 2 more. However, among the items with more complex syllable structures, the differences become more aware. Among CVCC nonwords, those with a high phonotactic probability resulted in 32 errors, but those with low probability bi-phones in 46, which is already a difference of 14 errors. The difference in error rates on the CCVC stimuli was with 31 again higher: 60 errors were created on low bi-phone probability nonwords, and 29 on high probability nonwords. Among CCVCC nonwords, where the largest difference was expected, indeed 23 errors were made with high and 59 errors with low phonotactic probability nonwords, what makes a difference of 36. These numbers are summarized in the table below.

Template	Errors for “high”	Errors for “low”	Difference
CVC	39	41	2
CVCC	32	46	14
CCVC	29	60	31
CCVCC	23	59	36

Table 3: Errors for each Category

Statistical Analysis: The interaction of two independent variables, phonotactic probability (low/high), and syllable structure (CVC, CCVC, CVCC, CCVCC) was tested. The dependent variable was RT. All 25 subjects were included. No-responses were excluded. A univariate analysis of variance (ANOVA) of between subjects' effects and within subjects' effects was carried out.

Important for this experiment was how the independent variables syllable structure and phonotactic probability would interact. This interaction was significant between subjects ($F = 4.856$, $p = 0.002$), and within subjects ($p = 0.00$).

Between subjects, overall high phonotactic probability targets were reacted to faster (RT mean = 1141.772 ms) than low phonotactic probability targets (RT mean = 1203.784 ms). This factor was not significant between subjects ($F = 5.813$, $p = 0.095$), but within subjects ($p = 0.00$).

For the four different syllable structures that were tested, RT results were not important for this study, and not significant different between subjects ($F = 1.365$, $p = 0.402$), but within subjects ($p = 0.00$). The visible augmentation from slowest to fastest RT means growing parallel with a reduction of syllable complexity (CCVCC targets with 1211.729 ms being reacted to slower than on CVCC with 1174.831 ms and CCVC with 1165.372 ms up to fastest on CVC nonwords with 1139.080 ms) can also be traced back to length, which was not a matter of interest in this study.

A post-hoc pairwise analysis did not reveal significant differences between CCVCC, CCVC, and CVCC. Only CVC significantly behaves as a distinguishable group.

It turned out that with this serial recognition task the influence of sub-lexical phonotactics on recall can be tested.

Discussion:

An earlier study on CVC nonword recall revealed significant of lexical neighborhood density on STM performance. Sub-lexical phonotactics however did not influence recall (Roodenrys & Hinton 2002). C-cluster bi-phones are phonotactically stronger restricted than for example CV or VC sequences. Thus, it was hypothesized that complex syllables including C-clusters would demand more phonotactic processing than simple CVC syllables. The prediction for the outcome of this experiment was that for CVC syllables, sub-lexical phonotactics of low and high probability would not influence recall, but that for CCVC, CVCC, and CCVCC syllables it would. A further aim of this experiment was to find a task that would not involve production, but could test the effects of phonotactics. The result shows that the design of this task phonotactics efficiently can be tested.

As expected, the interaction between syllable structure and phonotactic probability was significant between subjects ($F = 4.856$, $p = 0.002$), and within subjects ($p = 0.00$). In accordance with our predictions, phonotactic probability becomes an influential factor in STM recall if C-clusters are involved. Nonwords with a complex syllable structure yield significantly slower RTs and more errors, if the phonotactic probability is low. Lexical neighborhood size was controlled for and hence ruled out as an influencing factor. Therefore the different RTs clearly demonstrate processing of sub-lexical phonotactics. Also length by itself does not account for the results, because the RTs on targets with high versus low probabilistic phonotactics differed significantly. It shows that sub-lexical phonotactic restrictions are mentally represented, and this grammatical knowledge about probabilities of C-clusters can actively be used for processing: It directly influences STM recall. Because lexical neighborhood has been excluded as a factor, these results provide evidence for a probabilistic phonotactic grammar at a sub-lexical level. This phonotactic grammar could be represented by hierarchically ranked OT constraints.

The findings made with this experiment however are already very informative and contradict earlier studies, who assumed sub-lexical phonotactics to be non-influential on processing (e.g. Roodenrys & Hinton 2002).

However, this study does not allow drawing any conclusions on the importance of lexical neighborhood densities in processing C-clusters. It can be predicted that lexical neighborhood will become less important as a source of knowledge with increasing syllable complexity. Former studies that attributed strong lexical neighborhood effects to the STM recall of nonwords worked with CVC stimuli. Lexical neighborhood size however is negatively correlated with word length. The more complex the syllable is the fewer neighbors are available (Storkel 2004:215). It can be predicted that the listener will only rely on lexical neighborhood knowledge in processing CVC, which do not provide informative phonotactic grammar. Thus, a reciprocally proportional distribution should be expected: the more phonotactics can be fallen back on the less lexical neighbors should play a role. This will have to be tested in a next experiment.

One could argue now that the bi-phone statistics that were used for the creation of the stimuli were taken from statistics over lexical databases, and thus also correlate with the lexical knowledge in a speaker's mind. However, it is more likely that the results are triggered by grammatical knowledge. This is revealed in the different performances on nonwords dependent on the syllable template.

Nonwords containing C-clusters, which are phonotactically stronger restricted than CV or VC sequences yielded an effect of sub-lexical phonotactic processing.

It can be concluded that sub-lexical phonotactics are strongly connected with processing C-clusters. Because Cs carry important information for lexical access (Bonatti et al. 2005), it can be assumed that lexical acquisition is correlated with sub-lexical phonotactics. If this can be confirmed has to be found out in future studies.

3. Summary

In section 1. of this chapter it was described that a correlation between phonotactics and lexical acquisition has been searched and approved in studies on L1 acquisition. This motivates the assumption that a similar connection could influence L2 lexical acquisition. L2 learners have difficulties with acquiring L2 grammar. If phonotactic knowledge is grammatical, it will explain non-native speakers' problems memorizing and pronouncing foreign words correctly.

An experiment that tested the nature of phonotactic knowledge was described in section 2 of this chapter. The task was particularly designed for the purpose of later tests with L2 learners, because previous research has never tested L2 phonotactics, so no task had been available. This experiment revealed heavier problems for Dutch speakers to recall nonwords composed of low phonotactic probability bi-phones the more these were phonotactically restricted by constraints that govern inside the syllable structure. So, this study provides evidence that probabilistic phonotactics are processed sub-lexically. It will be possible to use this task to test how phonotactics are learned in an L2 in future research.

D. Conclusion and future plans

Phonotactics aid lexical acquisition, as has been shown in several studies (Gathercole et al. 1999; Gathercole et al. 2001, Storkel & Rodgers 2000, Storkel 2001). Whether this supportive phonotactic knowledge is represented at the sub-lexical level, which would entail a grammatical nature, or if it is represented at the lexical level, deduced as chunks from stored phonological word-forms, is contentious.

To attribute phonotactics a grammatical character, it is presupposed that grammar is psychologically real. Some research however argues against this view (e.g. Tomasello 2003). On this non-grammar assumptions ground researches on phonotactics that argue for a purely associatively learned nature of phonotactics, emerging from abstractions from the mental lexicon (e.g. Saffran et al. 1996a, 1996b; Nimmo & Roodenrys 2002). This MA thesis grounds its assumptions on the Pinkerian division of "words and rules", namely the grammar and the lexicon (1991). Building up on this theory, phonotactic knowledge about phoneme sequences could have a grammatical representation at the sub-lexical level (e.g. Vitevitch & Luce 1999).

My assumption was that prior research that argued against a grammatical nature of phonotactics (e.g. Roodenrys and Hinton 2002) could not have shown a grammatical involvement because of their stimuli selection. Most research on phonotactics has been working with simplex syllables. Phonotactic restrictions however are not that strong in onset-nucleus, or nucleus-coda-relations. I assumed that complex syllables would demand a stronger involvement of grammatical phonotactics.

I conducted a serial recognition experiment, testing Dutch speakers' recall performance on monosyllabic nonwords. These nonwords were of either high or low phonotactic probability. 4 different syllable structures were tested: CVC, CVCC, CCVC and CCVCC. It turned out that with increasing syllable complexity the probability of phonotactics had a stronger impact on recall. This demonstrates that probabilistic phonotactics are processed sub-lexically.

How this knowledge arrives at the sub-lexical level cannot be answered with this research. It could be that phonotactics emerge from the lexicon, as proposed by Pierrehumbert (2003) and Pater and Coetzee (2005), and that the grammatical component is only derived at the sub-lexical level. This however would not explain how knowledge about illegal phoneme sequences could be mentally represented, and we know that such knowledge is used for speech segmentation (e.g. McQueen 1998). If the lexicon only stored words and morphemes, it would not contain information, which is illegal in a language. More research will be needed to answer this question.

For learning an L2, this still raises some yet unanswered questions. It is known that L2 learners have difficulties in producing and perceiving C-clusters that are illegal in their L1, especially if they are illegal by rule, if their L1 syllable template does not provide the cluster (e.g. Davidson 2003). It could be the case that these difficulties result from an incapability to acquire L2 phonotactic grammar. L2 learners are known to have difficulties memorizing procedural knowledge, and try to balance this out by using the declarative memory (Ullman 2005).

In this MA thesis I constructed, why this could have fatal consequences for lexical acquisition. If it is C-clusters, being strongly restricted by phonotactic constraints, that L2 learners mostly have problems with, they exactly struggle with linguistic units that are directly connected with the lexicon. In B.4. I argued that apparently consonants are carriers of lexical information, whereas vowels are carriers of syntactic information (view Bonatti et al. 2005 for a similar statement). If L2 learners fail to re-rank phonotactic constraints and instead over-rely on lexical information, their capability of using phonotactics to bootstrap the lexicon will be very reduced. If this is the case, I will try to answer in future research.

Therefore, a first experiment will be run to test the effects of lexical neighborhood on C-clusters. Again only Dutch speakers will be tested. A new list of stimuli will have to be created, which will be similar to those of the first experiment, but controlling for phonotactic probability and offering high versus low lexical neighborhood density.

Afterwards, experiments with non-native speakers of Dutch can be started. It is planned to start out with Russian and Farsi speakers of Dutch. This offers interesting insights. The Farsi inventory of C-clusters is more restricted than the Dutch. Farsi does not allow branching onsets, but allows branching codas. We can thus predict heavy problems for Persians acquiring Dutch onset clusters. We will see, whether they rely on lexical or sub-lexical knowledge. If they rely on lexical knowledge, this could account for the problems speakers from phonologically less complex languages have with L2 C-clusters. They would fail acquiring "grammatical" phonology by wrongly harking back to "lexical" phonology.

Russian has more C-clusters than Dutch. The Dutch inventory of C-clusters can even be considered being a sub-set of Russian. The probability distributions however are different. It will be interesting to see, whether the Russian learner of Dutch is guided by lexical or sub-lexical knowledge to annex the non-native probability distributions.

A direct comparison of the two groups will show, whether it is easier to acquire the phonotactic "grammar" of a second language, if the native language comprises this grammar already. In order to draw conclusions about the development, high proficient speakers will be compared to either low proficient L2 learners or speakers that do not have any knowledge of Dutch.

In this experiment, I will exclude CVC stimuli and only work with CCVC, CVCC, and CCVCC nonwords. 4 sets of nonwords will be created testing the following conditions:

1. High probabilistic phonotactics and high lexical neighborhood density
2. High probabilistic phonotactics and low lexical neighborhood density
3. Low probabilistic phonotactics and high lexical neighborhood density
4. Low probabilistic phonotactics and low lexical neighborhood density

This was not possible for the first experiment, because Dutch does not have CVC nonwords of high phonotactic probability, but with low lexical neighborhood density. The advantage of using complex syllable templates only is that these provide enough nonword stimuli of each condition. Using such a set of stimuli will allow for testing more precisely which factors influence processing and learning within one experimental setting.

After that, it is planned to run serial recognition recall experiments with native speakers of Japanese and Modern Hebrew. Then not monosyllables but bi-syllables will be tested in order to find out more about the origin of knowledge of long-distance relationships between consonants, their acquirability in an L2 and influences on lexical acquisition.

E. References

Altmann, G.T.M. (2002): Learning and development in neural networks – the importance of prior experience. *Cognition*, 85, B43-B50.

Bailey, T.M., and Hahn, U. (2001): Determinants of wordlikeness: Phonotactics or lexical neighbourhoods? *Journal of Memory and Language*, 44, 568-591.

Balota, D.A., Paul, S.T., and Spieler, D.H. (1999): Attentional control of lexical processing pathways during word recognition and reading. In: Garrod, S., Pickering, M. (Eds.): Language Processing. Hove, UK: Psychology Press Ltd., 15-57.

Bauer, L. (2001): Morphological Productivity. Cambridge: CUP

Beckman, M.E., Munson, B., and Edwards, J. (in press): Vocabulary growth and the developmental expansion of types of phonological Knowledge. In: Cole, J. and Hualde, J. (eds.): Laboratory Phonology 9. Mouton de Gruyter.

Bertram, R., Pollatsek, A., and Hyönä, J. (2004): Morphological parsing and the use of segmentation cues in reading Finnish compounds. *Journal of Memory and Language*, 51, 325-245.

Best, C. (1999): Native-language phonetic and phonological constraints on perception of non-native speech contrasts. *The Journal of the Acoustical Society of America*, 105 (2), 1034.

Boersma, P., and Hayes, B. (2001): Empirical tests of the gradual learning algorithm. *Linguistic Inquiry*, 32(1), 45-86.

Booij, G. (2002): Prosodic restrictions of affixation in Dutch. In: Booij, Geert, and Marle, Jaap van (eds.): Yearbook of Morphology 2001. Dortrecht: Kluwer Academic Publishers, 183-201.

Bradlow, A.R., Pisoni, D., Akahane-Yamada, R., and Tohkura, Y. (1997): Training Japanese listeners to identify English

/r/ and /l/: IV. Some effects of perceptual learning on speech production. *Journal of the Acoustic Society of America*, 101 (4), 2299-2310.

Bybee, J. (1995): Regular Morphology and the Lexicon. *Language and Cognitive Processes* 10, 425-455.

Cholin, J., Schiller, N., and Levelt, W. (2004): The preparation of syllables in speech production. *Journal of memory and language*, 50, 47-61.

Chomsky, Noam (1968): Language and Mind. Harcourt.

Content, A., Kearns, R., and Frauenfelder, U. (2001): Boundaries versus onsets in syllabic segmentation. *Journal of Memory and Language*, 45, 177-199.

Cutler, A., and Norris, D. (1988): The role of strong syllables in segmentation for lexical access. *Journal of Experimental Psychology: Human Perception and Performance*, 14, 113-121.

Davidson, L., Smolensky, P., and Jusczyk, P. (2004): The initial and final states: Theoretical implications and experimental explorations of richness of the base. In: Kager, R., Zonneveld, W., and Pater, J. (eds.): Fixing Priorities: Constraints in Phonological Acquisition. Cambridge: Cambridge University Press.

Davidson, L. (2003): The Atoms of Phonological Representation: Gestures, Coordination, and Perceptual Features in Consonant Cluster Phonotactics. PhD Dissertation, John Hopkins University.

Dupoux, E., Kakehi, K., Hirose, Y., Pallier, C., and Mehler, J. (1999): Epenthetic vowels in Japanese: A perceptual illusion? *Journal of Experimental Psychology: Human Perception and Performance*, 16, 77-91.

Elsen, Hilke (1999): Auswirkungen des Lautsystems auf den Erwerb des Lexikons – eine funktionalistisch-kognitive Perspektive. In: Meibauer, J. And Rothweiler, M. (eds.): Das Lexikon im Spracherwerb. Tübingen, Basel: UTB Franke, 88-105.

Flege, J. (1987): The production of "new" and "similar" phones in a foreign language: Evidence for the effect of equivalence classification. *Journal of Phonetics*, 15, 47-65.

Fodor J. A., and Pylyshyn, Z. W. (1988): Connectionism and cognitive architecture: A critical analysis. *Cognition*, 28, 3-71.

Frauenfelder, U., and Schreuder, R. (1992): Constraining psycholinguistic models of morphological processing and representations: The role of productivity. In: Booij, G., and Marle, J. van (Eds.): Yearbook of Morphology 1991. Dortrecht: Kluwer Academic Publishers, 165-183.

Frisch, S., Large, N. and Pisoni, D. (2000): Perception of wordlikeness: Effects of segment probability and length on the processing of nonwords. *Jounal of Memory and Language,* 42, 481-496.

Fromkin, V. A. (1971): The non-anomalous nature of anomalous utterances. In: Victoria Fromkin (ed.): Speech Errors as Lingustic Evidence. The Hague: Mouton, 215-161.

Gathercole, Susan E., Pickering, Susan J., Hall, Melanie, and Peaker, Sarah M. (2001): Dissociable lexical and phonological influences on serial recognition and serial recall. *The Quarterly Journal of Experimental Psychology*, 54A, 1-30.

Gathercole S., Frankish, C., Pickering, S., and Peaker, S. (1999): Phonotactic influences on short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 25, 84-95.

Goldsmith, J. (1976): An overview of autosegmental phonology. *Linguistic Analysis*, 2, 23-68.

Gupta, P., and MacWhinney, B. (1997): Vocabulary acquisition and verbal short-term memory: Computational and neural bases. *Brain and Language*, 59, 267-333.

Haunz, Chr. (2002): The Role of Speech Perception in the Adaption of Loanwords, 1-12. In: http://www.ling.ed.ac.uk/~pgc/ archive/ 2002/proc02/haunz02.pdf.

Hay, J.B. (2000): Courses and Consequences of Word Structure. Ph.D. Dissertation Northwestern University.

Halle, P., Segui, J., Frauenfelder, U., and Munier, Chr. (1998): Processing of illegal consonant clusters: A case of perceptual assimilation? *Journal of Experimental Psychology: Human Perception and Performance* 24, 592-608.

Hulme, C., Maughan, S., and Brown, G. (1991): Memory for familiar and unfamiliar words: Evidence for a long-term memory contribution to short-term memory span. *Journal of Memory and Language*, 30, 685-701.

Jusczyk, Peter, Luce, P.A., and Charles-Luce, J. (1994): 'Infants' Sensitivity to Phonotactic Patterns in the Native Language'. *Journal of Memory and Language*, 33, 630-645.

Jusczyk, P.W., Friederici, A.D., Wessels, J.M.I., Svenkerud, V.Y., and Jusczyk, A.M. (1993): Infants' sensitivity to the sound patterns of native language words. *Journal of memory and language*, 32 (3), 402-420.

Jusczyk, Peter (1992): Developing Phonological Categories from the Speech Signal. In: Ferguson, C.A., Menn, L. and Stoel-Gammon, C. (eds.): Phonological Development: Models, Research, Implications. Maryland: Timonium, 17-64.

Kampen, J. van (1997): First Steps in Wh-Movement. PhD-Dissertation, Utrecht University.

Kochendörfer, G. (2005): Studien zum Spracherwerb in neuronalen Modellen. Teil 4: Lexikon. http://www.cortical-linguistics.de

Leather, J. (1999): Second language speech research: An introduction. In: Leather, J. (ed.): Phonological Issues in Language Learning. Oxford: Blackwell, 1-11.

Luce, P. and Pisoni, D. (1998): The neighbourhood activation model. *Ear and Hearing*, 19, 1-36.

Lugt, A. van der (1999): From Speech to Words. Njimegen: MPI Series.

Marcus et al. (1999): Rule Learning by Seven-Month- Old Infants. *Science* 283, 77-80.

McCarthy, John J. (1981): A Prosodic Theory of Nonconcatenative Morphology. In: Goldsmith, John A. (ed.): Phonological Theory. The essential Readings. Oxford: Blackwell, 162-184.

Mattys, S.L., White, L., and Melhorn, J. (2005): Integration of multiple speech segmentation cues: A hierarchical framework. *Journal of Experimental Psychology: General* 134 (4), 477-500.

Marslen-Wilson, W. (1999): Abstractness and combination: The morphemic lexicon. In: Garrod, Simon, and Pickering, Martin (eds.): Language Processing. Hove, UK: Psychology Press Ltd., 101-119.

McQueen, J. (1998): Segmentation of continuous speech using phonotactics. *Journal of Memory and Language* 39, 21-46.

Newport, E.L., and Aslin, R.N. (2004): Learning at a distance: I.Statistical learning of non-adjacent dependencies. *Cognitive Psychology*, 48, 127-162.

Nimmo, L., and Roodenrys, S. (2002): Syllable Frequency effects on phonological short-term memory tasks. *Applied Linguistics* 23, 643-659.

O'Brien, I., Segalowitz, N., Collentine, J., and Freed, B. (in press): Phonological Memory and Lexical, Narrative, and Grammatical Skills in Second-Language Oral Production by Adult Learners. To appear in *Applied Psycholinguistics.*

Pater, J., and Coetzee, A.W. (2005): Lexically specific constraints: Gradience, learnability, and perception. *Proceedings of the 3rd Seoul International Conference on*

Phonology. Seoul: The Phonology-Morphology Circle of Korea, 85-119.

Pierrehumbert, J. (2003): Probabilistic phonology: Discrimination and robustness. In: Bod, R., Hay, J., and Jannedy, S. (eds): Probability Theory in Linguistics. MIT press, 175-228.

Peña , M, Bonatti, L., Nespor, M., Mehler, J (2002): Signal-Driven Computations in Speech Processing. *Science*, 298, 604-607.

Pinker, S. (1991): Rules of Language. *Science*, 253 (5019), 530-535.

Prince, A.S. (1984): Phonology with Tiers. In: Goldsmith, John A. (ed.): Phonological Theory. The essential readings. Blackwell:Massachusetts, Oxford. 1999, p. 137-62.

Pylkkänen, L., Stringfellow, A., and Marantz, A. (2002): Neuromagnetic evidence for timing of lexical activation: An MEG component sensitive to phonotactic probability but not to neighborhood density. *Brain and Language* 81, 666-678.

Roelofs, A., and Schiller, N. (2004): Produzieren von Ein- und Mehrwortäußerungen, Max Planck-Institut für Psycholinguistik, Tätigkeitsbericht 2004, Arbeitsbereich Sprachproduktion, 655-658.

Rohde, A., and Tiefenthal, C. (2000): Fast mapping in early L2 lexical acquisition. Studia Linguistics 54(2), 167-174.

Roodenrys, S., and Hinton, M. (2002): Sublexical or lexical effects on serial recall of nonwords? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 28, 29-33

Rothweiler, M. and Meibauer, J. (1999): Das Lexikon im Spracherwerb. Ein Überblick. In: Meibauer, J. and Rothweiler, M. (eds.): Das Lexikon im Spracherwerb. Francke UTB: Tübingen, Basel, 9-31.

Rumelhart, D.E., McClelland, J.L. and the PDP Research Group (1986): Parallel Distributed Processing: Explorations in the Microstructure of Cognition. Volume 2. Cambridge, MA: MIT Press.

Saffran, J. R., Newport, E.L., and Aslin, R.N. (1996a): Word segmentation. The role of distributional cues. *Journal of Memory and Language*, 35, 606-621.

Saffran, J. R., Newport, E.L., Aslin, R.N. (1996b): Statistical learning by 8-month-old infants. In: Science 274, 1926-1928.

Schade, U. (1999): Konnektionistische Sprachproduktion. Wiesbaden: DUV.

Segui, J., Mehler, J., Frauenfelder, U. and Morton, J. (1982): The word frequency effect and lexical access. *Neuropsychologia*, 20 (6), 615-627.

Selkirk, E.O. (1982): The syllable. In: Goldsmith, John A. (ed.): Phonological Theory. The Essential Readings. Oxford: Blackwell, 328-350.

Service, E. and Craig, F.I.M. (1993): Differences between young and older adults in learning a foreign vocabulary. *Journal of Memory and* Language, 32, 608-623.

Service, E. and Kohonen, V. (1995): Is the relation between phonological memory and foreign language learning accounted for by vocabulary acquisition? *Applied* Psycholinguistics, 16, 155-172.

Sternberg, S. (1966): High speed scanning in human memory. *Science*, 5, 653-654.

Storkel, H.L., and Rogers, M.A. (2000): The effect of probabilistic phonotactics on lexical acquisition. *Clinical Linguistics & Phonetics* 14, 407-425.

Storkel, H.L. (2001): Learning new words: Phonotactic probability in language development. *Journal of Speech, Language, and Hearing Research*, 44, 1321-1337.

Storkel, H.L. (2003): Learning new words II: Phonotactic probability in verb learning. *Journal of Speech, Language, and Hearing Research*, 46, 1312-1323.

Storkel, H.L. (2004): Do children acquire dense neighbourhoods? An investigation of similarity neighbourhoods in lexical acquisition. *Applied Linguistics*, 25, 201-221.

Strange, Winfried (1992): Cross-language studies of speech perception. A historical review. In: Ferguson, C.A., Menn, L. and Stoel-Gammon, C. (eds.): Phonological Development: Models, Research, Implications. Maryland: Timonium, 3-45.

Taft, M., and Foster, K. (1975): Lexical Storage and Retrieval of prefixed words. *Journal of Verbal Learning and Behaviour*, 14, 638-647.

Tomasello, M. (2003): Constructing a Language. A Usage-Based Theory to Language Acquisition. Cambridge, Massachusetts, London: Harvard University Press.

Trommelen, M.T.G. (1983): The syllable in Dutch. With special reference to diminutive formation. Foris: Dortrecht. PhD. Thesis

Ullman, M.T. (2005). A Cognitive Neuroscience Perspective on Second Language Acquisition: The Declarative/Procedural Model. In C. Sanz (Ed.): Mind and Context in Adult Second Language Acquisition: Methods, Theory, and Practice. Washington, DC: Georgetown University Press, 141-178.

Yang, C. (2004): Universal Grammar, statistics or both? *Trends in Cognitive Sciences*, 8, 451-456.

Young-Scholten, M. and Archibald, J. (2000): Second Language Syllable Structure. In: Archibald, J. (ed.): Second Language Acquisition and Linguistic Theory. Blackwell, pp. 64-101.

Vitevitch, M., Luce, P., Charles-Luce, J. and Kemmerer, D. (1997): Phonotactics and syllable stress: Implications for the processing of spoken Nonsense words. *Language and Speech*, 40, 47-62.

Vitevitch, M., and Luce, P. (1998): When words compete: Levels of processing in perception of spoken words. *Psychological Science*, 9 (4), 325-329.

Vitevitch, M., and Luce, P. (1999): Probabilistic Phonotactics and Neighbourhood Activation in Spoken Word Recognition. *Journal of Memory and Language*, 40, 374-408.

Weber, A. (2001): Language-Specific Listening: The case of Phonetic Sequences. PhD Dissertation, MPI Series in Psycholinguistics, 16.

E. Appendix

Target non-words, phonotactic probability low versus high:

Low			High		
orthogr.	transcr.	template	orthogr.	transcr.	template
dwieng	dwiN	CCVC	blas	blAs	CCVC
dwoeng	dwuN	CCVC	breg	brEx	CCVC
dwoer	dwur	CCVC	brel	brEl	CCVC
dwung	dw}N	CCVC	brin	brIn	CCVC
dwuuw	dwyw	CCVC	broon	bron	CCVC
floeg	flux	CCVC	dreek	drek	CCVC
gloen	xlun	CCVC	froom	from	CCVC
glut	xl}t	CCVC	froon	fron	CCVC
knoeg	knux	CCVC	froot	frot	CCVC
knum	kn}m	CCVC	graak	xrak	CCVC
knung	kn}N	CCVC	groon	xron	CCVC
knup	kn}p	CCVC	klag	klAx	CCVC
kwieng	kwiN	CCVC	klar	klAr	CCVC
smuug	smyx	CCVC	kreg	krEx	CCVC
smuut	smyt	CCVC	krof	krOf	CCVC
snoem	snum	CCVC	praan	pran	CCVC
vloem	vlum	CCVC	prin	prIn	CCVC
vloeng	vluN	CCVC	slaam	slam	CCVC
wruuk	wryk	CCVC	slaar	slar	CCVC
zwoes	zwus	CCVC	traal	tral	CCVC
zwup	zw}p	CCVC	treng	trEN	CCVC
zwuug	zwyx	CCVC	trin	trIn	CCVC
zwuul	zwyl	CCVC	twil	twIl	CCVC
dwiengt	dwiNt	CCVCC	blast	blAst	CCVCC
dwoemt	dwumt	CCVCC	bleerk	blerk	CCVCC
dwoengt	dwuNt	CCVCC	brelt	brElt	CCVCC
dwoerg	dwurx	CCVCC	brint	brInt	CCVCC
dwungt	dw}Nt	CCVCC	dreeks	dreks	CCVCC
dwurf	dw}rf	CCVCC	frals	frAls	CCVCC
dwuuwt	dwywt	CCVCC	frens	frEns	CCVCC
gloemp	xlump	CCVCC	froons	frons	CCVCC
gloengt	xluNt	CCVCC	graakt	xrakt	CCVCC
glump	xl}mp	CCVCC	klark	klArk	CCVCC
knums	kn}ms	CCVCC	klient	klint	CCVCC
knungs	kn}Ns	CCVCC	kregt	krExt	CCVCC
knups	kn}ps	CCVCC	pliets	plits	CCVCC
snoemp	snump	CCVCC	prink	prINk	CCVCC
snoern	snurn	CCVCC	slaars	slars	CCVCC
snoerp	snurp	CCVCC	stenk	stENk	CCVCC

vloengt	vluNt	CCVCC	stert	stErt	CCVCC
vlumt	vl}mt	CCVCC	traals	trals	CCVCC
glups	xl}ps	CCVCC	trenk	trENk	CCVCC
vluums	vlyms	CCVCC	trogt	trOxt	CCVCC
vlups	vl}ps	CCVCC	trorm	trOrm	CCVCC
dwuungt	dwyNt	CCVCC	twekt	twEkt	CCVCC
gloemt	xlumt	CCVCC	twilt	twIlt	CCVCC
duul	dyl	CVC	beg	bEx	CVC
huul	hyl	CVC	deek	dek	CVC
kieng	kiN	CVC	foom	fom	CVC
koeg	kux	CVC	foot	fot	CVC
kuum	kym	CVC	gaak	xak	CVC
loeg	lux	CVC	has	hAs	CVC
loem	lum	CVC	kag	kAx	CVC
lut	l}t	CVC	laam	lam	CVC
mup	m}p	CVC	meef	mef	CVC
muut	myt	CVC	neek	nek	CVC
ruuk	ryk	CVC	raal	ral	CVC
soem	sum	CVC	raan	ran	CVC
soer	sur	CVC	rin	rIn	CVC
bir	bIr	CVC	rof	rOf	CVC
tir	tIr	CVC	roon	ron	CVC
vung	v}N	CVC	teg	tEx	CVC
wieng	wiN	CVC	teng	tEN	CVC
woer	wur	CVC	beel	bel	CVC
zaang	zaN	CVC	deef	def	CVC
zoes	zus	CVC	jaat	jat	CVC
zup	z}p	CVC	mel	mEl	CVC
zuug	zyx	CVC	seng	sEN	CVC
zuul	zyl	CVC	vook	vok	CVC
birg	bIrx	CVCC	beels	bels	CVCC
duulk	dylk	CVCC	beerk	berk	CVCC
huulm	hylm	CVCC	begt	bExt	CVCC
kiengs	kiNs	CVCC	deeft	deft	CVCC
koengs	kuNs	CVCC	deeks	deks	CVCC
kuump	kymp	CVCC	gaakt	xakt	CVCC
loemp	lump	CVCC	hast	hAst	CVCC
loerg	lurx	CVCC	jaart	jart	CVCC
lump	l}mp	CVCC	kark	kArk	CVCC
lumt	l}mt	CVCC	lient	lint	CVCC
mups	m}ps	CVCC	liets	lits	CVCC
noern	nurn	CVCC	meeft	meft	CVCC
soems	sums	CVCC	mels	mEls	CVCC
soerp	surp	CVCC	neeks	neks	CVCC
tirf	tIrf	CVCC	rals	rAls	CVCC
viengt	viNt	CVCC	rens	rEns	CVCC
vungt	v}Nt	CVCC	rogt	rOxt	CVCC
vurf	v}rf	CVCC	senk	sENk	CVCC

woemt	wumt	CVCC	sert	sErt	CVCC
woengt	wuNt	CVCC	tegt	tExt	CVCC
woern	wurn	CVCC	tekt	tEkt	CVCC
zaangt	zaNt	CVCC	torm	tOrm	CVCC
zuulm	zylm	CVCC	vookt	vokt	CVCC