Statistical Learning and Rule-based Learning in Bilinguals

Master's thesis

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1. Introduction

For years bilingualism has been considered a curse rather than a gift. Being raised with two languages instead of one was thought to confuse language learners linguistically and cause developmental delays as compared to normally developing monolingual infants. Nowadays, bilinguals have been proven to have several advantages over monolinguals, especially increased metalinguistic awareness resulting in improved language learning skills. As for lexical development, bilinguals do initially lag behind monolinguals, but this delay is somehow annulled in later years of childhood. How do bilingual learners come to equal monolinguals in vocabulary size after this initial delay? They appear somehow to be more efficiently processing the input which they receive.

Many modern linguists believe that statistical learning and rule-based learning are the primary driving forces behind speech segmentation. Infants are hypothesised to recognise patterns in the speech that they hear around them and form units from parts of this speech. Segmentation is thus, in this view, based on pattern finding. The task of finding and processing patterns in the input is controlled by two mechanisms, called statistical and rule-based learning. These two mechanisms serve different purposes in language acquisition. The interaction between language and implicit learning seems to be one regulated by constraints (Bonatti, Peña, Nespor & Mehler, 2005). In other words, certain linguistic factors give cues about one aspect of language learning, and others about a different aspect. Research has shown (e.g. Bonatti, Peña, Nespor & Mehler, 2005; Toro, Nespor, Mehler & Bonatti, 2008) that there is a functional difference between consonants and vowels. Consonants appear to be used primarily for the ‘recognition of lexical patterns’ (Bonatti et al., 2005: 452), whereas vowels serve to disclose grammatical properties of a language. Research has shown (Toro et al., 2008) that vowels are used to extract a structural regularity from continuous speech, whereas consonants are used to extract words. Thus, rule-based learning, focussing on vowels, is the extraction of a structural pattern from a speech sample and generalising this pattern to novel environments. On the other hand, statistical learning, focussing on consonants, is the computation of statistical relations in continuous speech to extract words. Speech segmentation is the first step in word learning. Infants must ‘discriminat[e] and remember[…] the different patterns’ (Jusczyk, 1997: 170) that they hear in speech, i.e. recognise where words begin and end, before they can link the correct meaning to each individual word. Therefore, statistical and rule-based learning are very important for lexical learning, although they are not the only relevant factors. Attention (e.g. Samuelson & Smith, 1998; Tomasello & Ferrar, 1986) and memory (e.g. Samuelson & Smith, 1998; van Daal, Verhoeven, van Leeuwe & van Balkom, 2008) are also important factors in word learning, but for reason of time restrictions these factors will not be discussed here. Considering statistical and rule-based learning to be the two primary mechanisms at the heart of lexical learning, it is possible that what allows bilingual learners to catch up with monolingual learners as regards vocabulary size is increased ability in those two mechanisms. Statistical and rule-based learning should, in that view, be seen as skills rather than mechanisms, susceptible to improvement with increased exercise due to necessity.

This Master’s thesis aims to reveal the statistical and rule-based learning ability of simultaneous bilinguals, in comparison with monolinguals. Differences in input might lead to an enhanced process of speech segmentation in adult bilingual language learners, such that increased experience with the task at hand might increase the ability to perform this task. It is like the old saying ‘practice makes perfect’. Possibly, experience enhances the learning ability in the same way as doing maths increases your mathematical ability. Someone who calculates everything on a calculator does not train his or her mathematical skills and will therefore be worse at math than if he or she were to calculate everything without the help of a calculator. The question that this Master’s thesis therefore hopes to answer is whether adult simultaneous bilinguals have increased statistical and rule-based learning ability compared to their monolingual counterparts.

An answer to this question will not only contribute to the growing body of research into bilingual language development and the bilingual brain, and add to our understanding of the differences between monolinguals and bilinguals, but it will also possibly provide new insight into the bilingual advantage for language learning.

After this first introductory chapter, chapter two will outline the theoretical background behind this research topic. It will discuss statistical and rule-based learning within the scope of usage-based linguistics, explain the process of lexical learning and illustrate the differences between monolingual and bilingual learners, as well as give a short outline of the methodology. Chapters three, four and five will present the methodology of experiments 1, 2 and 3, in that order, discussing participants, stimuli, and task and procedure. Each of these chapters will conclude with the results of the experiment. In chapter six, the general discussion will interpret the results and consider on their consequences for the hypothesis. It will discuss in detail what the results can tell us about how bilingualism affects implicit learning and in what way bilinguals differ from monolinguals in this respect. Another section of this chapter is devoted to possibilities and suggestions for future research, also elaborating on shortcomings in the present study. The conclusion will be presented in the seventh and final chapter.

2. Theoretical Background

2.1. Usage-based Linguistics

One of the greatest secrets of life has to be the human ability to learn language. How do children learn something that is so complex, so variable and, moreover, infinite? Over the years, many a researcher, psychologist and linguist has tried to find the ultimate explanation for the astounding phenomenon that is language acquisition. Language learning has boggled minds, as far as we know, since the time of Plato. In *Nemo*, he introduces the idea that all knowledge is innate. This idea is illustrated by the story of Socrates teaching an uneducated slave boy geometry. Plato's general line of thought is that we must know things *a priori*, because otherwise, how can we acquire them (Magnani, 2001: 3). Plato was probably the first to explore the *poverty of the stimulus problem*, sometimes also appropriately called *Plato's problem* (Chomsky, 1988: 3). The problem is basically the gap between knowledge and experience; how is it that man is able to learn so much, from only a limited amount of experience? (3-4)

The first modern theory of language acquisition developed from the branch of psychology called *behaviourism*, which provided the primary framework for language acquisition in the first half of the twentieth century (Byrne, 1994: 132). Byrne explains the general thought behind behaviourism by saying that '[t]he behaviourist takes minds not to be inner psychic mechanisms merely contingently connected with their outer behavioural effects, but to be (at least to a significant extent) constituted by those outer effects' (Byrne, 1994: 132). In linguistics, this translated itself into a theory in which children were thought to imitate language, and in which language acquisition is guided by stimuli and the language learner's responses (Malmkjær, 1991: 61).

It was in 1959 that Chomsky published his review on a book by Skinner, one of behaviourism's greatest proponents, arguing that some aspects of language are just too abstract to be learned by means of association and induction alone (Wittgenstein, 2003: 2). In subsequent years, Chomsky would introduce his idea of an innate language faculty enabling infants to acquire language, which would become the main tenet of *generative linguistics* (Wittgenstein, 2003: 2). Proponents of generative linguistics argued that it is impossible for children to go from nothing to adult speech with nothing other than information in the input they receive, and referred to this as the *poverty of the stimulus* argument. Rather, they argue, "basic linguistic representations are the same throughout all stages of child language development since they come ultimately from a single universal grammar" (Pinker, 1984; qtd. in Wittgenstein, 2003: 2). This is called the *continuity assumption.*

However, since the 1980's, people have been starting to reconsider the possibility that children are able to go from infant to adult speech without some innate language faculty. The first reason for believing so is that modern research has shown that children's ability to draw information from language input is much more extensive than behaviourism had ever held possible. Besides association and induction, children use a range of other cognitive skills in language learning. This new view of language learning is called *cognitive-functional linguistics* or *usage-based linguistics*, conveying the central idea "that language structure emerges from language use" (Wittgenstein, 2003: 5). Wittgenstein (2003: 3) states that there are two sets of skills that are critical for language learning. One is a combined set of skills referred to as *intention reading* and the other is *pattern finding*, or categorisation. An example of intention reading is the ability to follow someone's gaze, which can for instance help infants link words to objects. The other set of skills, pattern finding, is exactly what it says: the ability to recognise patterns in the given input.

One of the mechanisms that is at infants' disposal to track these patterns is called s*tatistical learning*, which Wittgenstein describes as 'the ability to perform statistically based analyses on various kinds of perceptual and behavioural sequences' (2003: 4). In the renowned study by Saffran, Newport and Aslin (1996a), the authors proved that distributional cues provide sufficient information for a learner to derive words from an artificial language.

The Artificial Language Learning paradigm has become particularly popular for testing hypotheses about natural language acquisitions. An artificial language allows scientists to control for the precise information such a language contains, depending on what the object of the investigation is. It also controls for existing knowledge. Gómez and Gerken (2000) write:

> "Artificial languages can be designed to test precise characteristics of learning. Knowing what infants can learn should, in turn, lead to more specific hypotheses about the actual mechanisms involved. Training infants on artificial languages also controls for prior learning. This latter feature is important because there is every reason to believe that learning begins even in the womb […], and such prior learning potentially affects all studies in which infants are tested on properties of their target language […]." (178-179)

By exposing participants to an artificial language and assessing what they have learned from it the role of hypothesised learning mechanisms can be put under test. Artificial languages contain a number of nonsense words and optionally a number of filler words and one or several language learning cues. Cues should give learners the information needed to acquire certain aspects of the artificial language. A learner might retrieve information for instance from the distribution of phonemes in a language, a language's stress pattern or other prosodic regularities, or the distribution of syllables. As a first step, infants acquiring a natural language will use these cues to segment the incoming speech stream into words. In later stages of the language acquisition process, learners will start to discover patterns relevant for the grammar of their language. Artificial Language Learning, in short, follows the same process as natural language learning, only focussed on one or several specific aspects of language (acquisition). This makes it the perfect paradigm to research the process that is language acquisition and the mechanisms used for it.

2.2. Statistical Learning & Rule-based Learning

Saffran, Newport and Aslin's 1996 study on statistical learning by infants is perhaps the most famous study using the Artificial Language Learning paradigm to simulate speech. With this study, the authors proved that statistical learning is definitely used to discover word boundaries in continuous speech. To demonstrate how infants are thought to perform statistical learning on the basis of distributional cues, Saffran et al. (1996b: 1927) give the illustrative example of the sound sequence *pretty#baby.* In this segment of speech, 'the transitional probability from *pre* to *ty* is greater than the transitional probability from *ty* to *ba*.', that is, the chance of *pre* being followed by *ty* is bigger than the chance of *ty* being followed by *ba*. After all, the *ty* part of the sound sequence *pretty* can be followed by theoretically any sound sequence, as in for instance *pretty#baby* but also *pretty#man* and *pretty#cool,* whereas the sound sequence *pre* can only be followed by a limited number of other sounds sequences, including *ty* but also for instance *vilege* (forming *privilege).* A *Statistical Probability* (TP) indicates what the chance is of A being followed by B on a scale of 0 to 1. Infants are able to track these statistical probabilities between segments and thus learn where to insert word boundaries in continuous speech.

The experiment performed by Saffran et al. tested 8-month old infants with a familiarisation-preference procedure, in which they presented them with auditory stimuli and determined how long they listen to each stimulus by looking at a blinking light; if the infants looked at the light relatively long, this was presumed to be the result of a novelty effect, indicating that participants were not familiar with this stimulus. First, the infants were exposed to an artificial speech stream generated by the repetition of four tri-syllabic nonsense *words* (e.g. *pabiku, tibudo*) Then, in the familiarisation-preference procedure, they were presented with four tri-syllabic strings. Of these strings, two were words from the artificial language and two were strings of syllables straddling word boundaries in the artificial language, called *part-words* (e.g. *tudaro, pigola*). The predication was that because infants would be able to compute the transitional probabilities between syllables, which were higher between words than within words, they would listen longer to the words than to the part-words. Results showed just that, indicating that infants can segment speech by computing its statistical properties.

After this first evidence of the statistical learning abilities of infants, many comparable studies were conducted to provide additional evidence for this claim. In this way, over the years, a great body of literature on infants' statistical learning ability has been created, making a strong case for the power of statistical regularity as a cue for speech segmentation. One of the earlier studies is based on the study by Saffran et al. The aim of this study by Aslin, Saffran and Newport (1998) was to narrow the results of the original study down to one interpretation only. As well as participants preferring words over nonwords because the TPs within words were greater than the TPs between words, there is also the possibility that this preference was caused by a higher frequency of the words in the artificial speech stream compared to the part-words. To eliminate this interpretation, in their experiment Aslin et al. adjusted the artificial language, so that of the four words, two occurred twice as often as the other two. This resulted in the frequency of the less common words being identical to the frequency of the part-words. Therefore, if infants still were to prefer these less common words over part-words in a head-turning preference task, this would indicate that this preference is based only on the difference in TP values, and not on frequency of occurrence. The result did in fact reveal this same preference, emphasising the power of statistical computation in infants.

Research has shown that adults are also able to compute statistical regularities in a speech stream. For instance, Saffran, Newport, Aslin, Tunick and Barrueco (1997) proved that adults and infants are equally able to derive words from continuous speech, even by incidental learning. The adult participants listened to an artificial speech stream made up of 300 tokens of 6 tri-syllabic nonsense words randomly organised, while they were drawing. They were not told a priori that the experiment was actually about language learning, or even had anything to do with the speech that they heard in the background. Afterwards, they participated in a two-alternative forced-choice task, where each trial presented one nonsense word and one word made up from syllables of the artificial speech stream which never occurred in that order, between which they had to choose. Results showed that the participants had a preference for the former items, from which the authors concluded that adult language learners can unconsciously perform a statistical learning task.

The second primary learning mechanism used to segment speech is *rule-based learning.* Rule-based learning, like statistical learning, is all about finding patterns in a stimulus. It differs from statistical learning though, in that it focuses on finding a general algebraic rule in the input, rather than calculating transitional probabilities between segments. Essentially, rule-based learning means tracking a generality in the input and generalising it to other environments.

An example of rule-based learning comes from a study by Marcus, Vijayan and Bandi Rao (1999). Marcus et al. recorded seven-month old infants' rule-based learning ability after exposure to an artificial language containing recurrent syllable patterns. So children were tested on their ability to track a rule from a speech sample. They were exposed to a two-minute speech sample containing one of two possible *conditions*. In the first condition, test words had an ABA pattern (e.g. *ga ti ga*), so children were expected to recognise that the first segment was always the same as the third segment, and always different from the second one.

In the ABB condition (e.g. *ga ti ti*), the final two segments were identical and the first was different. In a head-turning preference task, infants listened to 12 words, all containing different syllables from the ones in the familiarisation phase. Half of those words had the same order as the items in the condition that the infant was exposed to. The other half had the order of the other condition, which the infant was not exposed to. The children were predicted to show a preference for words exhibiting the same pattern over words with a different order. A longer looking time for the *inconsistent* words confirmed this prediction.

Gomez and Gerken (1999) also seek to emphasise the ability of infants to generalise grammatical knowledge. They created an artificial grammar, in which certain strings of words were possible, i.e. grammatical, whereas other strings were impossible, i.e. ungrammatical. In their first two experiments, their approximately 12-month old infant participants were exposed to samples of less than 2 minutes generated by the artificial grammar. Of the 23 possible strings, 10 strings were used in two sets of five, combined in three different orders, thus resulting in 6 different familiarisation trials. Using the head-turn preference procedure, they were then tested on their ability to generalise the grammar. The test items were 10 new grammatical and 10 ungrammatical strings. The grammatical strings were new, in the sense that they were strings possible in the artificial grammar but not yet used in the familiarisation phase. The ungrammatical strings were ungrammatical because they could not be generated by the artificial grammar. Infants proved able to generalise the grammar they had acquired in the familiarisation phase, as they preferred grammatical strings, strings that complied with the artificial language rules, over ungrammatical strings in the test phase.

In a later study, Peña, Bonatti, Nespor, and Mehler (2002) tested adults on their generalisation skills. In their own words, "[t]his study emphasizes the specific computational abilities that favour the discovery of the structural properties of a corpus. Conceivably, in the absence of such abilities, language would be impossible to acquire". Peña et al. created an

‘AXC language’, which was structurally predictable in that an element A in a tri-syllabic nonsense word was always followed by an element C, separated by a variable element X. The artificial speech stream was made up of these ‘words’ on the one hand and ‘part words’ on the other. Part words were tri-syllabic words composed of the same syllables as the words, but not arranged in the AXC order. In one of Peña et al.’s experiments, the two-alternative forced-choice task, in which participants must choose one word of two possible options, had the participants choose between part words and a third category of words, namely ‘rule words’. These rule words were items that had not appeared in the artificial language, but were congruent with the AXC rule. Peña et al. found that participants preferred rule words over part words, even though the rule words were entirely new to them, only when minor gaps were inserted in between words in the familiarisation phase, and length of exposure to the artificial language was relatively short. They concluded, therefore, that there are two computational modes which a language learner can switch between, depending on the given signal. The computational mode where an algebraic-like computation is made to detect a structural regularity, as opposed to the mode where statistical patterns are the focus of attention, is switched on when silent gaps occur in the speech stream.

Toro, Nespor, Mehler and Bonatti (2008) also tested adults on their rule-based learning ability. Specifically, their study supports the hypothesis that adult participants use vowels to extract a structural regularity from continuous speech, but are unable to extract the rule with consonant information only. The reverse is also true, as participants use transitional probabilities between consonants to segment speech into words. Their results were obtained by exposing the participants to 10 minutes of artificial speech and then having them perform a two-alternative forced-choice task. The artificial language was made up of 12 tri-syllabic familiarisation words and a number of filler words. The familiarisation words were generated by two consonantal frames, namely t-p-n and b-d-k, and an ABA vowel pattern using the vowels a, e and o. The filer words, either one-, two- or three-syllabic, were randomly made up of the syllables of the familiarisation words. Examples of familiarisation words are *tapena, tepone* and *bodako.* Examples of filler words are *ta, boke* and *nobapo.* An example of what the artificial speech stream looked like is *taponabotebedaketatopenonobapobadeka*. As regards the test phase, the items in the forced-choice task were of 4 different categories, namely *words*, *part-words, rule-words* and *nonrule-words.* Part-words were string straddling word boundaries in the artificial language (e.g. *penabe*, *bodeko*), and rule-words in addition retained the ABA vowel pattern but contained vowels that did not occur in the artificial language (e.g. *biduki, tupinu*) whereas nonrule-words had a divergent vowel pattern (e.g. *biduku, tupuni*). Participants were successfully predicted to prefer words over part-words and rule-words over nonrule-words. Also, a reversal of the role of consonants and vowels, consonants following an ABA pattern and vowels being predictable based on TP, was correctly predicted to eliminate this preference. Thus, these results revealed that in addition to statistical learning, adult language learners are able to extract a grammatical rule from continuous speech with their rule-based learning ability.

A similar study is that of Bonatti et al. (2005). In their first experiment, they presented adult French-speaking participants with an artificial speech stream made up of tri-syllabic nonsense words. Crucially, in this artificial language the TPs within words were higher than the TPs between words, but identical for vowels. Results showed that participants had a preference for words over part-words. Thus, the participants were able to exploit the TPs between consonants to track words form the continuous speech stream. In a series of other experiments, Bonatti et al. demonstrate that participants do not have a preference for words over part-words when the TPs for vowels, but not for consonants, are higher within words than between words. They concluded that adult learners can only track words from continuous speech on the basis of consonant TPs and not on the basis of vowel TPs.

2.3. Lexical Learning in Bilinguals

Beside distributional cues used for statistical and rule-based learning, infant lexical development can also be guided by phonological and phonotactic cues, such as the occurrence of strong syllables (Jusczyk, Houston & Newsome, 1999: 202-203), stress patterns and other acoustic and prosodic cues, for instance pitch, syllable lengthening and pausing (Gerken, 1996: 412). However, the most common linguistic view nowadays on lexical development in infants is that statistical and rule-based learning are the two most important mechanisms that guide this process.

Crucially, all infants segment speech in largely the same fashion and at largely the same rate. Even though there is some individual variation, all infants reach the same milestones of lexical learning after roughly the same periods of time (Hoff, 2006: 234-235). The long-held view that bilinguals must lag behind monolinguals because of the strain of having to learn two languages instead of one has long been refuted. The few delays that are still said to occur in bilinguals as compared to monolinguals, for instance that they start speaking slightly later on average (Cappiello & Gahagan, 2009: 1508) and that they have a higher frequency of errors when forming the past tense of verbs (Nicoladis, 2003: 170; qtd. in Nicoladis, 2008: 170), usually prove to be temporary (Leung & Kao, 1999: screen 4) and have a direct relation to the limited linguistic input for each language (Pearson, Fernández, Lewedeg & Kimbrough Oller, 1997: 51). The task of having to learn two languages instead of one does not delay linguistic development because of cognitive, social or emotional confusion. The human mind is capable of acquiring two languages at the same time and this does not seem to cause any cognitive damage (Hakuta, 1990: 1). In fact, in recent years several advantageous cognitive effects of bilingualism have been attested, such as increased metalinguistic awareness (Bialystok, 2004), increased attentional control (Bialystok, 1999) and enhanced cognitive control abilities (Kovács & Mehler, 2009). The terms *bilingual* and *bilingualism* will be used here to refer to simultaneous bilingualism only, not to additive bilingualism or (early) second language learning. A simultaneous bilingual is defined as a person who has been exposed to two languages from birth or early childhood.

As for word learning, bilinguals have repeatedly been proven to have no inferior lexical development compared to monolinguals, provided that the total vocabulary, the combined number of words of the two languages, is measured (Genesee, 2006: 6-7). In fact, most studies (e.g., Junker & Stockman, 2002; Pearson et al., 1993; qtd. in Patterson, 2004: 1215) comparing monolingual and bilingual vocabulary size find that bilinguals' total vocabulary is similar to or larger than monolinguals' vocabulary. The results of at least one study (Allman: 2005) indicate that bilingual children (age 2;4-6;6) have on average a larger total vocabulary than their monolingual counterparts. A similar observation has been made by Nicoladis (2003), who found that 'bilinguals might score higher on average than half the vocabulary of monolinguals' (qtd. in Nicoladis, 2008: 170). In any case, adult bilinguals can attain the same vocabulary size in one of their languages as monolinguals do (qtd. in Nicoladis, 2008: 170). Therefore, even though bilinguals initially have a delay in lexical development when the individual development of their two languages is considered (Uccelli, 200: 226), they will eventually catch up with their monolingual counterparts. Possibly, bilinguals' lexicons might match those of their monolingual counterparts already at a very young age, as suggested by the results of Nicoladis (2003; qtd. in Nicoladis, 2008: 170), whose bilingual participants were only 3 to 4 years of age at the time of testing. Again, the initial delay in lexical development for bilinguals is not due to linguistic confusion from having to learn two languages instead of one, but to limited input for each language (Pearson et al., 1997: 51)

2.4. The Learning Task for Bilinguals

Although bilinguals are no longer thought to be less developed than monolinguals linguistically, it is not difficult to see why people might have thought this for such a long time. After all, bilinguals are faced with having to learn twice as much as their monolingual counterparts with no additional input. As for lexical development, bilingual infants would need to learn every word that a monolingual learns in two languages instead of one. From a statistical and rule-based learning or, more generally, a pattern-finding point of view, bilinguals would have to segment speech containing twice the amount of speech segments. Put simply, a Dutch monolingual infant will have to learn that segments A and B can or cannot combine to form a word. For instance, combining *ko* and *nijn* makes *konijn*. The infant will learn this because the combination of these two segments has a relatively high TP. On the other hand, it will learn that *zwart* and *ko*, let’s call them segments C and A, cannot combine to form a word, because the combination of these two segments has a relatively low TP. A Dutch-English bilingual infant will additionally have to learn that two additional segments, from the other language can also either form a word or have a word boundary separating them. Thus, *ra* and *bit*, segments D and E, also form a word, and *black* and *ra*, segments F and D, do not. So bilinguals are burdened with double the amount of statistical and rule-based learning in comparison with monolinguals.

Furthermore, it could be argued that word learning is also a more complex task for bilingual infants, provided that they consider the input that they receive as one entity and not as two. That is, if there is some period of time starting from birth that bilingually raised children do not yet have the ability to separate their two languages. In the late 70s and early 80s, many linguists were of the opinion that bilingual new-borns and infants are initially unable to differentiate between their two languages (e.g. Genesee, 1989; Volterra & Taeschner, 1978; qtd. in Lanza, 1993: 197). This theory was referred to as *The Unitary*

Language System Hypothesis (Genesee, 1989; qtd. in Lanza, 1993: 197). Proponents of this theory claimed that code mixing was proof of bilinguals' inability to keep their two languages apart. The most extreme representatives of this hypothesis were Volterra and Taeschner. In their 1978 study, they claimed that bilingual infants did not use so-called translation equivalents until they were approximately 3 years of age. Translation equivalents are words with a different form but the same meaning in bilinguals' two languages, and Volterra and Taeschner took the lack of these translation equivalents in their data of 22- and 18-month old bilingual infants as support for a single language system in the first months of life. Specifically, they claimed that:

> "In the first stage the child has one lexical system which includes words from both languages. …, in this stage the language development of the bilingual child seems to be like the language development of the monolingual child. …
>
> In the second stage, the child distinguishes two different lexicons, but applies the same syntactic rules to both languages.
>
> In the third stage the child speaks two languages differentiated both in lexicon and syntax…" (Volterra & Taeschner; qtd. in Genesee, 2005: 891).

It was not until 1995 that a large-scale scientific study (Pearson, Fernandez & Oller) first suggested that bilinguals separate their languages from very early on. They stated that studies such as Volterra and Taeschner's were methodologically weak, citing as an example the limited quantity of data. Their results showed that bilinguals did in fact produce translation equivalents from very early on. Their study proved that bilinguals already produce translation equivalents from the moment that they have an active vocabulary size of 12 words or less. This observation demonstrates that bilingually raised infants "do not avoid learning two words for the same referent when those words are in different languages" (Werker, Byers-Heinlein & Fennell, 2009: 3650). Therefore, these translation equivalents were seen as proof that young bilinguals do differentiate between the lexicons of their two languages.

Another observation about bilingual infants that was taken as support for a single-language system was code-mixing. It was thought that this indicated that they could not keep their two languages apart. Later, other interpretations consistent with a dual-language system emerged. Genesee (1995), for instance, suggested that code-mixing was simply a device used by bilingual infants to make optimal use of their linguistic resources, to be able to express themselves as well as possible (Genesee, Nicoladis & Paradis, 1995: 619-629; qtd. in Du, 2010: 137). Code-mixing was no longer seen as sufficient proof for a single-language system. From here on, more studies provided support for an early separation of languages by bilinguals.

Moreover, evidence was found for all aspects of language acquisition, not only lexical, but also grammatical and phonological. For instance, Bosch and Sebastián-Gallés (2001) tested 4-month old Spanish-Catalan bilinguals on their auditory differentiation skills. The infants first listened to sentences spoken in either one of their languages and then participated in a head-turning preference test. Consistent with the expected novelty-preference, they listened longer to sentences spoken in the language that they were not familiarised with than to those consistent with the familiarisation language. As is the case for monolingually raised infants, this ability to separate auditorily presented stimuli, i.e. languages, seems not be present from birth, but rather develops somewhere in the first months of life (Mehler et al., 1988; Nazzi et al., 1998; Nazzi et al., 2000; Nazzi & Ramus, 2003; qtd. in Werker et al., 2009). As for syntactic development, the results of a number of studies focusing on different syntactic features (Döpke, 1997; Meisel, 1990; Meisel & Müller, 1992; Paradis & Genesee, 1996; qtd. in Nicoladis, 1998: 108) all indicate that the syntactic systems of a bilingual's two languages develop autonomously from the beginning, when syntax is first observed. Paradis and Genesee (1996), for instance, examined data of 2-year old French-English bilingual children on the emergence and of functional categories. Specifically they looked at the acquisition of finiteness, agreement and negation properties. Their data showed that there is no interaction, in the form of transfer, acceleration, or delay in acquisition, between the children's two languages, and the authors therefore conclude that the children must have two linguistic systems that develop autonomously.

Researchers such as Goodz (1986) and Genesee (1989) have found that it is primarily prosodic cues, such as intonation, stress and rhythm, that enable bilingual infants to distinguish between their two languages (qtd. in Goodz, 1994: 63). Languages belong to different rhythmic classes, and the prosodic and rhythmic characteristics of a language enable both a monolingual and a bilingual infant to tell this language apart from other languages (Nazzi, Bertoncini, & Mehler, 1998). How early exactly a bilingual infant differentiates its two languages also depends on the amount of exposure and more crucially the specific language combination of the bilingual infant. Moreover, bilingual infants are actually able to distinguish between their two languages very early on even when they are rhythmically similar. Bosch and Sebastián-Gallés (2001) performed an experiment with Spanish-Catalan bilinguals. First, infants with a predominantly Spanish speaking mother were exposed to Spanish passages in the familiarisation phase, whereas infants with a Catalan speaking mother listened to passages in Catalan. Afterwards, they listened to both Spanish and Catalan stimuli, and their looking times were measured in a head-turning preference test. The results showed that a novelty effect, as revealed by longer looking times, occurred when the infants heard stimuli of the language that they did not hear in the familiarisation phase. A novelty effect did not occur when the infants were exposed to stimuli of the language in the familiarisation phase. Thus, bilingual infants are able to differentiate between two languages from the age of 4 months, even when these languages are rhythmically similar. Possible information that young bilinguals use to differentiate between two languages in addition to prosodic cues therefore include metrical cues, about the stress pattern, and distributional cues (Bosch & Sebastián-Gallés, 2001: 46).

However strong the evidence in favour of a dual language system for bilingual language acquisition and very early differentiation of a bilingual's two languages, it is not certain if a bilingual infant can already separate its two languages from birth. It is hence very well possible that there is a period of time in the first weeks or months of a bilingual language learner's life that he or she does not have two different storages for the two different languages. During that period, a bilingual infant might store the input it receives in one system and process it accordingly.

Let us now return to the fictive Dutch-English bilingual infant. In a scenario as described above, where it is unable to differentiate between the two languages in the first weeks or months of its life, it would initially calculate the crosswise statistical relations between English and Dutch segments. After all, code-mixing can cause, in this case, Dutch and English segments to occur subsequently, either intrasententially or intrasententially, and the bilingual infant does not know that these segments belong to different languages and cannot be combined at all. Only if a bilingual infant would somehow be able to keep the one language separate from the other would it save itself the trouble of calculating the transitional probabilities between segments from different languages. There are some parents who claim that they adhere completely and definitely to the one-parent one-language principle. This scenario might enable a bilingual infant to match the use of one language entirely to one of its parents, and the other language to the other parent. However, with reference to this separation of the input, Goodz (1989) has shown that of the bilingual parents in her study, "despite strong avowals to the contrary, no parents were able to maintain a strict parent/language separation" (Goodz, 1989: 41). Assuming therefore that bilingual infants initially mix their two languages instead of keeping them separate, they are faced with the task of learning more different combinations of units, making the learning task more complex. In an example, the Dutch-English bilingual infant would, because it initially considers the input as one entity, automatically calculate the probability of *zwart* and *ra*, and *black* and *ko* forming a word, if it hears either of these two segments used after each other (in a sentence where code-mixing occurs, e.g. *Kijk, wat een mooi zwart rabbit* or *Look, what a beautiful black konijn*).

Voorbeeld rule-based learning (more complex)?

To illustrate how this works more generally, consider the following situation. When monolingual infants hear segments G and H in their input, they will only calculate what the transitional probability is between G and G, H and H, G and H and, the reverse, between H and G. Hypothetically, bilingual infants who would make a distinction between their two languages will need to calculate the transitional probability between G and G, H and H, G and H, and H and G, but also for segments I and I, J and J, I and J, and J and I from their other language. Thus, they will make 8 instead of 4 calculations. Finally, bilinguals who do not make a distinction between their two languages will not only calculate what the transitional probability is between segments G and G, H and H, G and H, and H and G, and between segments I and I, J and J, I and J, and J and I, but will also have to calculate the transitional probability between segments G and I, G and J, H and I, H and J, I and G, I and H, J and G, and J and H. In total, then, they will make 16 calculations. Considering that infants are probably exposed to hundreds of speech segments each day (van de Weijer, 2002: 280-281) the number of additional computations that an undifferentiating bilingual infant must make compared to a differentiating infant keeps increasing.

Storing the input in one language system also causes TPs to change. Because the infant that does not differentiate between its two languages considers each combination of segments as a possible word, thus calculating its TP, this influences TPs at word and morpheme boundaries. For this infant, segment G can be followed by segments G, H, I and J, whereas for an infant that separates the two languages, segment G can only be followed by segments G and H. Because more combinations with segment G are possible for the undifferentiating infant than for the differentiating infant, each individual combination including segment G is relatively less frequent. That means that the TP between these two segments is lower than it is for the differentiating child. There is also the special case of segments which occur in both languages, for instance *do*. In English, *do* can form a word with for instance *main* or *cile*, making *domain* and *docile.* In Dutch, *do* can form a word with for instance *de* or *cu*, making *dode* and *docu.* The undifferentiating infant perceiving these segments in these four combinations will calculate what the TP of *do* plus any of the four other segments is. Again, this will give lower TPs than if the infant were to compute only the TP between those segments that occur in the same language.

In sum, as regards statistical learning, bilingual infants are faced with both a doubled and a more complex learning task than monolingual infants are. They have to perform the same task as monolinguals, yet only have half the input and processing resources available for each language, and in addition are faced with input that is more complex than that of their monolingual counterparts. As regards rule-based learning, a similar claim can be made. Bilingual infants will need to extract rules from two different languages and thus make more different generalisations than monolingual learners have to make. As with statistical learning, the learning task might also be more complex if indeed infants are initially unable to separate their two languages. When an undifferentiating infant is exposed to mixed utterances, it could detect patterns that combine segments from both languages and are thus not actually possible patterns in one of the individual languages. For instance, it might recognise that *aan het X -ing*, in a sentence such as *Papa is aan het working* or *Ik ben aan het cleaning*, is an AXC pattern. However, bilinguals might benefit less from their additional experience with rule-based learning than from their extra experience with statistical learning, because the former requires less input (Endress & Bonatti, 2007). Hence, more input might have a less powerful effect on a bilingual's rule-based learning ability than on their statistical learning ability.

Usage-based accounts of language acquisition place much emphasis on input as a critical factor for linguistic development. It is sometimes even argued that a 'critical mass of exemplars' might be needed for a language learner to acquire certain aspects of language (Marchman & Bates, 1994; qtd. in Tomasello, 2000: 67). Usage-based Linguistics predicts, then, that bilingual learners should lag behind monolingual learners in lexical development in each of their individual languages because of constraints on input (Paradis, Nicoladis & Crago, 2007: 497). As the total amount of input is equal for monolingual and bilingual infants, according to Usage-based Linguistics the two should equal each other in total vocabulary size. This prediction is borne out for bilinguals, who initially match monolinguals in total vocabulary size but have lower vocabulary sizes in each individual language. However, bilinguals can eventually come to approach or even match monolinguals' vocabulary size for each of their languages, despite the limited input that they receive (Eilers, Pearson & Cobo-Lewis, 2006; qtd. in Nicoladis, 2008: 170). Also, as Nicoladis's (2003; qtd. in Nicoladis, 2008: 170) results suggest, they probably start catching up with their monolingual counterparts at a relatively young age. Therefore, bilingual learners must develop increased word learning capacity. As segmentation of speech is the first step in word learning, these observations suggest is that bilinguals might somehow become more efficient at using the primary skills guiding segmentation, namely statistical and rule-based learning.

2.5. The Effect of Experience on the Learning Task

Current literature has not yet researched the role of bilingualism in statistical and rule-based learning ability. Much research has, however, been performed on the advantage of bilingualism on third language learning. The current view is that the increased metalinguistic awareness that is linked to bilingualism results in increased cognitive skills such as problem-solving. Such skills have been proven to benefit third language learning: “The development of competence in two or more languages can result in higher levels of metalinguistic awareness. These facilitate the acquisition of language by exploiting the cognitive mechanisms underlying these processes of transfer and enhancement” (Jessner, 1999: abstract). In other words, metalinguistic awareness is key in “how to learn to learn language” (1). Because bilinguals have increased metalinguistic awareness, they are better at learning a third language than monolinguals are. Possibly, increased statistical and rule-based learning ability might also be a contributor to the bilingual advantage in third language learning. In situations where the third language is acquired in a natural manner, without specific instruction, the learner’s need to segment speech streams could profit from enhanced statistical and rule-based learning ability.

Lany and Gomez (2008) have proven that infants’ rule-based learning ability can be increased by prior experience with the learning task. In their study they asked whether learners can generalise abstract structural regularities in a novel vocabulary to analogous and to more complex structures, accelerating learning of a subsequent vocabulary. In their first experiment, they discovered that prior exposure to a pattern (aX bY) facilitated the acquisition of a similar pattern in a novel vocabulary for adult learners. The second experiment proved the second part of their predictions to be true. In this experiment, one group of learners was first exposed to an artificial language stream containing a simple aX bY pattern before listening to an artificial language stream with a more complex acX bcY structure. The other group was given no prior experience. Results showed that prior experience with the simple pattern accelerated learning of the more complex pattern. A follow-up study (Lany, Gomez & Gerken, 2008) tested infants and found similar results.

The studies by Lany and Gomez, and Lany, Gomez and Gerken focus on the ability to generalise a pattern to a novel language, which is a different situation altogether from statistical learning. With rule-based learning, learners can possibly use knowledge from patterns that they already know to their advantage when they need to learn new patterns. With statistical learning, this is not an option. Prior experience with statistical learning does not provide a learner with useful knowledge for calculating transitional probabilities between segments of a novel language. There is simply no way to generalise or transfer in statistical learning. Each statistical calculation over a new set of segments has to be made with no information other than the transitional probability between those segments. In other words, for each new calculation, a learner needs to begin completely from scratch.

Nonetheless, what these studies show in general is that increased experience with a learning task can facilitate a comparable learning task. In the studies by Lany and Gomez, and Lany, Gomez and Gerken this previous experience consists of existing linguistic knowledge that can be used in a novel language, whereas increased experience in statistical learning increases a person's skill instead of expanding its knowledge.

2.6. Hypothesis & Prediction

The question that this thesis hopes to answer is whether adult bilinguals are better at statistical and rule-based learning than adult monolinguals. As regards statistical learning, bilingual adults have had more experience than monolingual adults, due to the increased quantity and complexity of the lexical learning task for bilingual infants as compared to monolingual infants. Consequently, this added experience might increase their statistical learning ability. Hebbian theory says that repetition of a mental activity induces growth and increases the efficiency of the relevant cells in the brain (Hebb, 1949). Hebb's rule says that "[w]hen an axon of cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B, is increased" (Hebb, 1949: 62) Thus, the neural network can be expanded and improved by repeated stimulation by means of a frequently performed activity. The more frequently an activity is repeated, the more the part of the neural network that is used for this activity is stimulated, which increases the efficiency and rate with which the cells relevant for this activity are used. In other words, the brain can be trained by experience. With this in mind, an interesting fact is that bilingualism delays the onset of dementia by, on average, 4 years (Bialystok, Craik & Freedman, 2007). This observation strengthens the idea of bilingualism stimulating the brain. The added mental exercise that bilinguals have compared to monolinguals apparently keeps the brain healthy.

For bilingual infants, the quantity of statistical calculations that need to be made for the purpose of word learning is greater than it is for monolingual infants, namely doubled. This increased quantity might raise the efficiency of the relevant skill, thus resulting in enhanced statistical learning ability. Moreover, as the statistical calculations made by bilingual infants are more complex than those made by their monolingual counterparts, this is also hypothesised to enhance bilingual infants' statistical learning ability. The same can be said for rule-based learning: increased experience with extracting patterns from speech might enhance the rule-based learning ability of bilingual learners. Again, this experience could come both from bilinguals having to extract more rules from their input, more or less twice as much, as well as them being faced with a more complex rule-based learning task due to the initial lack of separation of their two languages and, thus, of the different patterns in the two languages. This claims something entirely different from the studies by Lany and Gomez, and Lany, Gomez and Gerken. In these studies, the rule-based learning advantage results from specific knowledge from the learner's exposure to comparable patterns, whereas I argue for a facilitative effect due to general experience with rule-based learning.

The hypothesis is, then, that the added experience with statistical and rule-based learning that bilinguals have, both by increased quantity and complexity of the input, results in increased statistical and rule-based learning ability.

Because this study researches bilinguals' statistical and rule-based learning ability, one challenge is to form a homogeneous group of bilingual participants. For this, a clear definition of the term *bilingual* and *bilingualism* must first be established. In this Master's thesis, these terms will be used interchangeably with *simultaneous bilingual* and *simultaneous bilingualism.* Over the years, different researchers have maintained different definitions and criteria for calling someone a simultaneous bilingual (Serratrice, 1996: 170). For instance, McLaughlin (1978; qtd. in Serratrice) considers a person a simultaneous bilingual when this person has first come into contact with the second language at age three or earlier. Others, such as Padilla and Lindholm (1984; qtd. in Serratrice) argue against an arbitrary cut-off point and claim that simultaneous bilingual is only the correct term when a person has been exposed to both languages from birth. De Houwer (1990; qtd. in Serratrice) proposes yet another definition. She suggests that we can only speak of simultaneous bilingualism when the second language is introduced no later than a week after exposure to the first language, and further adds the criterion of daily exposure to both languages.

Although to this day there is still little consensus about the exact age that is the endpoint of a critical period for language acquisition, "a child at the age of four knows the basic properties of the first language" and must therefore be regarded a second language learner and not a first language learner (Guasti, 2002; qtd. in Unsworth, 2010: 3-4). Also, when the age of exposure to the second language is higher than 3, segmentation of speech by means of statistical and rule-based learning will have largely finished. Therefore, learners exposed to a second language after this age will not have the massive extra experience with statistical and rule-based learning that learners with an earlier age of exposure do. Age 3 is hence considered to be a safe maximum age of exposure until which a bilingual can be considered a simultaneous bilingual instead of an additive bilingual. People who have been exposed to a subsequent language after the age of 3 are thus considered second language learners, and were excluded from participation in this study.

Although the study by Toro et al. is considered a satisfactory test of statistical and rule-based learning ability, there is a point of critique, which concerns their selection of consonants. No explanatory notes are provided on why these particular consonants, and in this particular order, were chosen. This concern is legitimate since Onnis, Monaghan, Richmond & Chater (2005) have shown that the distribution of phonemes can influence the segmentation of words in speech. A word boundary can be prompted, for instance, when the pause before an unvoiced plosive is significantly longer in synthesised speech than it is in natural speech. This pause preceding an unvoiced plosive might be a cue for segmentation, in that the plosive is thought to be the start of a new word. Because the stimuli of the study by Toro et al. contain unvoiced plosives both at the onset, the nucleus and the coda, it is not likely that this cue affects segmentation much.

Finn and Hudson Kam (2008) have shown that in an artificial language learning paradigm, L1 knowledge can affect segmentation. It is therefore possible that Italian phonology or phonotactics influenced segmentation of the artificial language for the Italian participants in the study by Toro et al., since the authors do not give indication of having accounting for transfer from the L1. More important for this study is that Dutch phonology might also have an effect on the monolingual Dutch participants' segmentation. Boll-Avetisyan and Kager (2008) have shown that OCP-Place influences segmentation for monolingual speakers of Dutch. OCP-Place is "a constraint targeting sequences of consonants that share place of articulation" (Kager, 2010: abstract). In other words, speakers of Dutch will prefer sequences in which consonants with the same place of articulation do not follow each other. Thus, Dutch speakers will tend to insert a word boundary in between two consonants with the same place of articulation. Crucially, no consonants with the same place of articulation follow each other directly in the two consonantal frames of the words that Toro et al.'s artificial language is made up of. Thus, a succession of two consonants with the same place of articulation can only occur between words, due to the filler words, and not within words. Therefore, in this respect, the consonantal distribution would facilitate Dutch speakers' recognition of the words in Toro et al.'s artificial language because, due to the influence of OCP-Place, they would insert word boundaries between words. However, since sequences of two consonants with the same place of articulation are rare in this artificial language, the influence of the OCP-Place constraint on segmentation should be limited.

To test the hypothesis that bilinguals are better at statistical and rule-based learning than monolinguals due to increased experience, bilinguals and monolinguals will be compared in their statistical and rule-based learning ability. In this study, I duplicate the experimental design of the 2008 study by Toro et al. on the functional differences between vowels and consonants. This study researched both statistical learning and rule-based learning by creating an artificial language containing nonsense words based on consonantal frames indicative of statistical dependencies, and vowel patterns indicative of an algebraic rule, and testing on the detection of both separately. The former was done by participants' execution of a segmentation test, and the latter by their participation in a generalisation test, after having listened to the artificial language.

The first experiment in this Master's thesis will replicate, with a few changes, experiment 1 in the study by Toro et al. Thus, a control group of monolingual participants will be tested on their statistical and rule-based learning ability by means of a two-alternative forced choice task, divisible in a segmentation test and a generalisation test. They are expected to perform above chance on both parts of this forced-choice task, thereby contributing to the vast amount of literature demonstrating that implicit learning, more specifically, statistical and rule-based learning, plays a significant role in word learning ability. A positive result will also ensure that bilinguals can be properly tested on their statistical and rule-based learning skills, without flaws in the methodology affecting their performance.

3. Experiment 1

3.1. Participants

First, a control group consisting of 22 Dutch monolinguals (20 female, 2 male) had to be tested to ensure that replication of the study by Toro et al. was possible. In the Netherlands, students are educated in English from the fifth year of primary school, although for as little as 30 minutes per week, and throughout secondary school. German and French are also taught for a varying number of years in secondary school. In addition, the Dutch media are fairly internationally-oriented. Therefore, hardly anyone in the Netherlands is truly monolingual. For the purpose of this study, any individual was considered who has not been exposed to a language other than Dutch from a young age. Only people who had not been extensively exposed to another language than Dutch before entering secondary school were allowed to participate. Exposure to additional languages in primary school and from the media was disregarded.

Another issue of concern is determining what the most desirable age span is for the participants. Concepts such as development of the brain and vocabulary development could have an effect on the participants' performance in the experiment. According to Moore & ten Bosch (2009: 3), vocabulary growth stagnates almost completely between the ages of 12 and 14. Also, based on a longitudinal MRI study, Giedd, Blumenthal, Jeffries, Castellanos, Liu, Zijdenbos, Paus, Evans and Rapoport (1999) report that: "Gray matter in the frontal lobe increased during pre-adolescence with a maximum size occurring at 12.1 years for males and 11.0 years for females, followed by a decline during post-adolescence […]. Parietal-lobe gray matter followed a similar pattern, increasing during pre-adolescence to a maximum size at age 11.8 years for males and 10.2 years for females, followed by decline during postadolescence […]" (861). The ages at which brain development and vocabulary development more or less stagnate are thus highly similar. At age 14, brain development should be relatively stable as regards the areas associated with language learning. To be safe, participants were selected from age 18, when both male and female participants can be presumed to have completed puberty (Lee, 1980: abstract). During puberty, an elevation in the secretion of hormones changes the neural network (Sisk & Zehr, 2005: screen 3). Thus, when puberty is completed the neural network should be stable. Subsequently, a maximum age had to be determined. In this way, the optimal age range for cognitive processing can be established. Although there has been some debate on the age of onset of cognitive decline, a recent 7 year longitudinal study by Salthouse (2009) has shown that cognitive decline already starts at the age of 27. Based on these findings, only participants from the age of 18 to 26 were considered. The average age of the monolingual participants is 21.8 years. Participants were retrieved from the UiL-OTS subjects' pool. All participants received 5 Euro for their participation.

3.2. Stimuli

The stimuli were adopted from Toro et al. (2008). In their experiment, stimuli for the familiarisation phase were 12 CVCVCV nonsense words, referred to from now on as familiarisation words, concatenated into a speech stream. They are divisible into two sets of consonantal frames. The first consonantal frame is *t-p-n* and the second is *b-d-k*. Consonants have been chosen over vowels because they have been proven (Toro et al., 2008) to be the most reliable cue for statistical learning; learners do not use vowels to track statistical relations. Vowels are used in rule-based learning (Toro et al., 2008); when vowels are distributed according to a rule, they guide the learner in word learning. In the study by Toro et al. the vowels follow an ABA pattern. That is, the first and the final vowels in the nonsense words are identical, whereas the vowels in the second syllable are different. The vowels used for creating the artificial language were [a], [e] and [o]. In the test items of the generalisation test, [i] and [u] were used.

However, because the participants in the study by Toro et al. had a different native language than the participants that are recruited in this Master's thesis, Italian versus Dutch, lexical differences might have an effect on the participants' performance. As regards the Italian participants, Toro et al. provide no information on whether any Italian words were present in the artificial speech stream which might have affected participants' segmentation. To check whether the artificial language did not contain a too large number of existing Dutch words, a script was used to extract real words of Dutch occurring in the CELEX Lexical database (Baayen, Piepenbrock & van Rijn, 1995) from the artificial language. The result was that the artificial language did contain a large number of Dutch words. Also, of these words a relatively large number were longer words, either CVCV or longer, which are most likely to be perceived in a speech stream.

For this reason, I altered the phoneme inventory of the artificial language, but as little as possible, in order to create a version with significantly fewer Dutch words. In doing so, care had to be taken to ensure that no long, CVCV or longer, Dutch words would occur in the test items. Several attempts were made to create an improved artificial language without making any drastic changes to the original one. Changing one of the consonants was considered a too radical alteration to the original artificial language and was thus not considered as an option. A first effort to improve the artificial language was switching the order of the consonants in the consonantal frames, resulting in 35 possible new artificial languages. None of these, however, were a significant improvement on the original artificial language, neither in the number of Dutch words it contained nor in the perceptibility of those words when listening to the speech stream.

In a second attempt to decrease the number of Dutch words in the artificial language, I looked into replacing one of the vowels with a vowel not present in the original phoneme set. The original vowels, [a], [e] and [o] are positioned at equally large distances from each other in the vowel triangle, making them highly discernible from each other. In order to maintain this distinctiveness, the new vowel should not be too far removed on the vowel triangle from the original vowel it replaces. Also, because the duration of all vowels in the artificial language is synthetically kept equal, no short vowels could be used. Finally, the vowel [i] received no consideration because it is a derivative word of the Dutch diminutive *–je* and could therefore affect segmentation considerably, because participants might have a tendency to segment the speech stream in words ending with [i]. These criteria eliminated all possible options but one: substituting [u] for [o]. After having replaced [o] with [u], all 36 possible alternative artificial languages were tested on the natural quality of their sound and on the number of Dutch words they contained. All 36 new languages were a significant improvement to the original, so to stay as close to the original artificial language, the original vowel distribution was maintained whilst only replacing [o] with [u]. The resulting list of nonsense words is presented in table 1.

An additional feature of the study by Toro et al. is that they included a number of self-named *noise syllables* in the artificial speech stream. These filler syllables, as they will be called from now on, were inserted so that the consonantal frames did not follow each other uninterruptedly, increasing the naturalistic quality of the artificial language. The insertion of filler words causes the transitional probabilities both between words, at the word boundary, and within words to decrease. Filler words are one, two and three syllable parts of the nonsense words. They were randomly distributed and make up 30% of the artificial language stream. With these filler syllables inserted, the TPs for within-word consonants were 0.7 whereas the TPs for between-word consonants were 0.16. Within-words vowel TPs were 0.4 and between-words vowel TPs ranged from 0.16 to 0.4. An example of the artificial speech stream is *tapunabutebedaketatupenunubapubadeka.*

The test phase contains 24 items. In the segmentation test, 8 test pairs were given (16 test words). Each pair consisted of one *word* and one *part-word*. Of the words, 4 were chosen from *the t-p-n* consonantal frame and the other 4 from the *b-d-k* consonantal frame. Part-words are syllable sequences occurring in the artificial language in which a word boundary is crossed. Both words and part-words retain the ABA vowel pattern, so that a distinction between the two choices could be made only on the basis of statistical learning and not on the basis of rule-based learning. The total list of words and part-words is given in table 2.

The generalisation test was made up of only 8 different test words. Each of the 8 words was repeated once so that the total number of test items was identical to the number in the segmentation test. Each test pair includes a *rule-word* and a *non-rule-word*. Rule-words have the ABA vowel pattern, however, the vowels in this pattern did not occur together in that order in the artificial speech stream. The non-rule-words have a divergent vowel structure. Half of the non-rule-words have an AAB vowel pattern and the other half has an ABB vowel pattern. All words in the generalisation test retain either one, in equal proportions, of the consonantal frames. Therefore, performance on this test measured differences in rule-based learning only. Because [o] was replaced by [u] in the familiarisation words of which the artificial language is made up, all [u]'s in the rule-words and non-rule words in the generalisation test have been substituted with [o]'s. The total list of rule-words and non-rule words can be viewed table 2.

All stimuli were synthesised using the speech synthesis software MBROLA, with syllable F0 set to 240 Hz and keeping the phoneme duration constant at 120 ms each. The speech stream was faded in and out with the acoustic analysis software PRAAT.

TABLE 1: *Familiarisation words*

t-p-n consonantal frame	**b-d-k consonantal frame**
tapena	badeka
tapuna	baduka
tepane	bedake
tepune	beduke
tupanu	budaku
tupenu	budeku

TABLE 2: *Test pairs in the Forced-choice task*

Forced-choice task			
Segmentation test		Generalisation test	
Words	Part-words	Rule-words	Non-rule-words
tapena	penabe	bidoki	bodiki
tapuna	dukatu	bodiko	bidoko
tupanu	paneba	tiponi	toponi
tupenu	dakuba	topino	tipono
badeka	nabuda		
bedake	katepa		
beduke	nebade		
budeku	kubadu		

3.3. Task and Procedure

The entire experiment was conducted in a soundproof booth. First, participants were instructed to listen to the artificial speech stream through headphones, which took 10 minutes, and to pay attention to any fictive words they might hear in it whilst listening. Directly afterwards, participants had to perform a two-alternative forced-choice task on a computer. In a two-alternative forced choice task, participants listen to any number of test trials. Each test trial auditorily presents two test items. Participants then have to choose one of these two items, before moving on to the next trial. This forced-choice task consisted of two separate tests. The *segmentation test* tested for lexical learning on the basis of statistical learning, using the transitional probabilities between consonants, and the *generalisation test* did the same on the basis of rule-based learning, assessing if vowels were used to generalise a rule. Finally, participants were asked to fill out a questionnaire, containing questions about their performance in the experiment –such as if they had recognised any Dutch words and if they adopted any particular strategy– and about their language background, for instance if they have any degree of proficiency in any languages other than Dutch and where they use these languages. The entire list of questions can be viewed in appendix A.

The test items in the forced-choice task were played to the participants in a random order. Participants were instructed to choose one of these two sound sequences based on which of the two they were most convinced of having heard in the artificial speech stream by clicking on the matching number, either one or two, on the screen. A 500-ms pause separated the two items in a pair and the next pair was played 2000 ms after an answer had been given.

3.4. Results and Discussion

Participants preferred words over part-words in the segmentation test by 56.3% (± 1.38). A one-way T-test revealed that this result was significant ($t(21) = 2.13$, $p < 0.05$ (0.045), so participants scored significantly above chance. Participants were able to segment words from a continuous speech stream by calculating the TPs between consonants. These results confirm existing literature demonstrating that adults can find words in speech by means of statistical learning.

However, with a mean score of 48.9% (± 2.18) participants did not perform above chance on the generalisation test. Thus, participants had no preference for rule-words over nonrule-words ($t(21) = -0.25$, $p > 0.05$ (0.81)). For some reason, these Dutch participants experienced much more difficulty in extracting a pattern from the vowels in the continuous speech stream than the Italian participants in the Toro et al. experiment did. Apart from replacing [o] with [u] no alterations have been made to the original artificial language or otherwise, and it is not probable that this alteration accounts for the difference between the two test groups. Therefore, this contrast is most likely caused by phonological differences between Dutch and Italian. Although it is not clear why Italian speakers should be better at rule-based learning at least with regard to this particular artificial language, one major difference between Dutch and Italian that might somehow have influenced the manner in which both groups of participants have performed is a sharp contrast in the number of vowels in both languages. Dutch has 15 vowels (Rie, van Bezooijen & Vieregge, 1995; qtd. in van Hout, Adank & van Heuven, 2000: 153) whereas the Italian dialect of the participants in the study by Toro et al. has only 5.

Because Italian has fewer vowels than Dutch, the expectation is actually that they would have had more trouble detecting the vowel pattern. The reason for this is that the more vowels a language has, the more informative each individual vowel is. In a language which has proportionally many consonants and few vowels, speakers could be expected to focus more on consonants than on vowels since the set of consonants can provide far more information than the much smaller set of vowels can. A higher number of consonants than vowels means more different possible consonant sequences than vowel sequences (Bonatti, Marcela Penã, Nespor & Mehler, 2007: 924). Thus, more different combinations of consonant, or patterns, are possible. Therefore, in a language with many consonants each individual consonant is more distinctive than it would be in a language with few consonants, because it is used less; each consonant has a more specific function. In this view, consonants can be argued to be more distinctive and informative than vowels. Thus, the Italian participants should be expected to perform worse than the Dutch participants, since they are predicted to focus less on the vowels in the artificial language than the Dutch participants. Therefore, there is no explanation for the two groups' performances.

Another possibility is that Dutch speakers were in a way misled by the low number of different vowels, only [a], [e] and [o], in the artificial language stream. Several participants indicated, following participation in the experiment, that they were focussing on hearing which vowels were and were not present in the speech stream. The Italian participants expect to hear a maximum of 5 different vowels and in the experiment they hear 3 of those 5 vowels. The Dutch participants expect to hear a maximum of 15 different vowels and also hear only 3 of those in the experiment. Relatively seen, therefore, the Dutch participants are satisfied in their expectation far less than the Italian participants were. It might be that the Dutch participants were in a way waiting for more vowels to occur in the artificial speech stream or particularly concentrated on the fact that only 3 of the 15 possible vowels seemed to occur in the speech stream. Perhaps the Dutch participants, more so than the Italian participants, were thus distracted from the actual task which is statistical and rule-based learning, because the vowel distribution confused them.

There is another major contrast between Italian and Dutch and it concerns isochrony. Whereas Dutch is a stress-timed language, Italian is a syllable-timed language. The artificial language is made up of open syllables of approximately equal length, and therefore most resembles a syllable-timed language in phonological structure. Therefore, in this respect, the artificial language has more resemblance to Italian than it does to Dutch. This resemblance might have facilitated segmentation for the Italian participants, resulting in their greater performance as compared to the Dutch participants who had no such advantage.

There is a final possible explanation for the overall better performance of the Italian participants compared to the Dutch participants. As Toro et al. provide no information on whether words were present in the speech stream, the participants' segmentation may have been affected by lexical effects, whereas such effects were excluded in the current study.

Of course it is impossible to make an exact replication of any experiment. Regardless of what caused the poor performance of the Dutch monolingual participants, experiment 1 has proved to be an unsatisfactory test for rule-based learning ability and attempts had to be made to improve it, before testing bilinguals. It was decided to design a second experiment to test Dutch monolingual participants on their statistical and rule-based learning ability. Therefore, some adjustment had to be made to the artificial language so as to facilitate the recognition of the ABA vowel pattern. Several modifications were considered, but the final decision was to decrease the noise in the artificial language by reducing the number of filler words.

Experiment 2 will test a new group of 16 monolingual students on their statistical and rule-based learning ability by exposing them to the altered artificial language, which has been adjusted so as to facilitate recognition of the ABA vowel pattern. The prediction is that participants will now perform above chance both on the segmentation and on the generalisation test.

4. Experiment 2

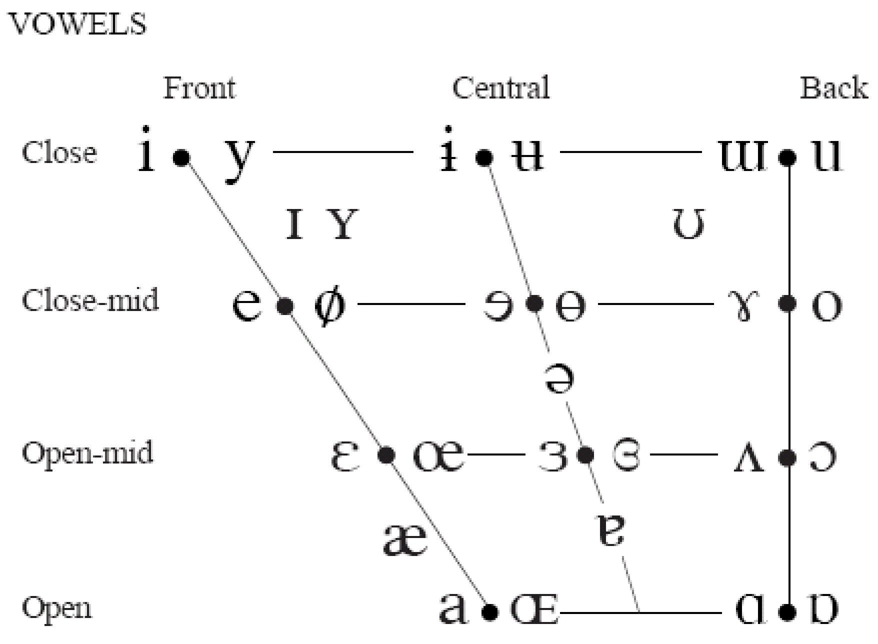
4.1. Participants

Participants were 16 monolinguals (15 female, 1 male) retrieved from the UiL-OTS subjects' pool. For reasons mentioned in chapter 3 participants were between the age of 18 and 26. Their mean age is 22.6 years. Participants received 5 euro for participation in the experiment.

4.2. Stimuli

To make the vowel pattern easier to detect for the participants, the stimuli used in experiment 1 had to be adjusted. Several options to facilitate detection of the pattern were considered. One possibility was to increase the variability of the middle vowel in the vowel pattern. Gómez (2002) investigated the influence of predictability between adjacent elements on the detection of non-adjacent dependencies. She found that for three-element strings, recognition of a non-adjacent dependency became easier when the predictability between adjacent elements, i.e. the first and the second and the second and the third element, decreased. Thus, when variability of the second element is increased, non-adjacent dependencies like those in the ABA pattern are easier to detect. One type of modification therefore entailed 6 different vowels in the second position of the words instead of 3 as in the original artificial language. Thus, each familiarisation word had a different middle element. I choose the vowels based on which vowels, in combination with the consonantal frames, produced the least Dutch words in the familiarisation words and in the total speech stream. The middle vowels were coupled with the vowels in first and third position based on acoustic similarity. Only vowels which were considerably distanced from each other acoustically, as portrayed in the IPA vowel chart, were combined in a familiarisation word.

FIGURE 1: *IPA Vowel Chart*



This adjustment was expected to make the vowel pattern more easily recognisable. However, a few people who were asked to listen to this artificial language indicated that they still experienced difficulty in extracting the rule from the continuous speech stream. For this reason, another modification to the artificial language in experiment 1 was considered. The study by Toro et al. is one of the few which has chosen to insert filler syllables into the artificial language (see also Shukla, Nespor & Mehler, 2007; Tagliapietra, Fanar, Collina & Tabossi, 2009). They reason, logically, that this will increase the naturalistic quality of the artificial language, as no human language has sentences in which a small group of words follow each other repeatedly without interruption of words outside that set. Small function words such as *the, a, is, will, and, but, my* and *he* and content words longer or shorter than 3 syllables will separate content words of 3 syllables in natural speech. Thus, to have the artificial language stream better resemble natural speech, Toro et al. added noise in the form of filler syllables to their stream of familiarisation words. In their original artificial language, filler syllables made up 30% of the total speech stream. As tested in a pilot, a higher percentage of filler syllables kept participants from detecting statistical regularities and from detecting the vowel pattern. Removing this noise from the speech stream would facilitate both statistical and rule-based learning, as TPs within words for consonants and vowels would increase and TPs between words would decrease. However, taking the filler syllables out of the artificial language would decrease the naturalistic quality of the speech stream. More importantly, because complete removal of the filler syllables resulted in an artificial speech stream in which familiarisation words simply follow each other, detection of the vowel pattern, and in effect also of statistical regularities, might become too easy for the participants and a ceiling effect may occur.

The final option, which was adopted, was reducing the number of filler syllables in the artificial language. This option was preferred over increased variability of the middle element because even with maximum variability, a different vowel in the middle position of each word, the recognisability of the vowel pattern in the speech stream improved only minimally. Reduction instead of complete removal of the filler syllables was chosen because complete removal might have caused the vowel pattern to be too clearly perceptible and thus result in a ceiling effect. A reduction of the filler syllables would create an artificial language that is still reasonably natural sounding, but yet with a reduction in noise such as would enable participants to better hear the ABA pattern. It did not both decrease the number of filler syllables in the artificial language and increase the variability of the middle vowel in the familiarisation words because I wanted to alter the artificial language of experiment 1 as little as possible. My expectation was that participants would be able to extract the pattern from the artificial speech stream without also increasing the variability of the middle element.

The stimuli for the familiarisation phase were thus the same as in experiment 1, the only exception being that some adjustments, most crucially a significant reduction, were made to the filler syllables. To enforce the natural sound of the artificial language stream, filler syllables were randomly inserted in between every 2 or 3 familiarisation words, instead of every other word. Also, to further facilitate recognition of the vowel pattern, only monosyllabic filler syllables were used. This resulted in an artificial language with 11.6 % filler syllables, as opposed to 30% in experiment 1. Within-word vowel TPs were increased to between 0.43 and 0.45, and between-word vowel TPs now ranged between 0.11 and 0.45. Of course, reduction of the filler syllables also increased the TPs of the consonants. Within-word consonant TPs ranged between 0.89 and 0.88 and between-words consonant TPs between 0.02 and 0.58.

As regards the test phase, the stimuli in the segmentation test were identical to those in experiment 1. For the generalisation test, the phoneme set was altered. Instead of 4 different rule-word/nonrule-word pairs, the generalisation test in experiment 2 contained 8 test items, an equal number to the test items in the segmentation test. The additional 4 test items were created by using [y] and [ø] in addition to [i] and [o]. Toro et al. were forced to limit the test items in the generalisation test to 4 for the simple reason that Italian only has 5 vowels, and the other 3 were already used in the familiarisation words. This limitation is however not necessary in this experiment, as Dutch has several more vowels to choose from. Thus, the forced-choice task could be strengthened by equalling the number of test items in the segmentation and the generalisation test. This could remove any possible confusion on the part of the participants because the test items would resemble each other less. Vowels [y] and [ø] were chosen because they are the only tense monophthongs of Dutch not yet used in the experiment. [u], [a] and [e] were used in the familiarisation words and [i]and [o] were already used in the test items. Instead of creating test words combining [y] with [ø], [y] was combined with [o] and [ø] with [i] because these pairs were acoustically less similar and because it resulted in better and more natural sounding test words. A list of the new test pairs in the generalisation test is presented in table 3.

The reason that this expansion of the test items in the generalisation was not already added into experiment 1 is because at the time, it was considered more important that the experiment remained as close to the study by Toro et al. as possible. Being compelled to adjust the experiment so that the vowel pattern would become more easily recognisable, adhering to the Toro et al. experiment became less important than creating a sound experiment which shows both participants' statistical and rule-based learning.

All stimuli were synthesised using MBROLA, with syllable F0 set to 240 Hz and keeping the phoneme duration constant at 120 ms each. The artificial speech stream was faded in and out with PRAAT.

TABLE 3: *Test pairs in the generalisation test of the Forced-choice task*

Forced-choice task	
Segmentation test	Generalisation test
Rule-words	Non-rule-words
bodyko	bydyko
bydoky	bodyky
topyno	typyno
typony	topyny
bidøki	bødøki
bødikø	bidøkø
bidøki	tøpøni
tipøni	tipønø

4.3. Task and Procedure

Task and procedure are identical to experiment 1.

4.4. Results and Discussion

Participants had no significant preference for words over part-words (M = 50.7%, ± 5.0, $t(16) = 0.17$, $p > 0.05$ (0.87)) nor for rule-words over nonrule-words (M = 52.2%, ± 5.0, $t(16) = 0.51$, $p > 0.05$ (0.61)). As in experiment 1, participants were not able to extract the

ABA vowel pattern from the artificial speech stream. The participants' score on the generalisation test was slightly higher than the score of the participants' in experiment 1, yet not significantly so. Apparently, the reduction of the filler syllables did not facilitate recognition of the pattern enough for rule-based learning to take place. Strikingly, performance on the segmentation test was actually poorer than it was in experiment 1, both in comparison with the total 22 participants as well as in comparison with the original 15 participants of experiment 1.

This result is remarkable, as participants in this experiment were expected to outperform participants in experiment 1. After all, reduced noise, in the form of fewer filler syllables, causes the TPs within words for vowels but also for consonants to increase. Thus, the environment for both statistical and rule-based learning is improved. Hence, the cause of the participants' equally poor performance as compared to the participants' performance in experiment 1 remains unclear. It is unlikely that participants in both experiments performed at chance and that it was merely a result of chance that the performance of the participants from experiment 1 exceeded that of the participants in experiment 2. After all, the mean score of the participants in experiment 1 rose significantly above chance after the test group was enlarged. At this point, I have no explanation for why the participants in experiment 2 performed worse than those in experiment 1, even though lower TPs should have facilitated both statistical and rule-based learning.

Because experiment 2 proved unsuccessful in testing for both statistical and rule-based learning, it was decided to test the bilingual participants on the artificial language of experiment 1. As monolingual participants did prefer words over part-words in experiment 1 as shown by the results of the segmentation test, the design of the artificial language in experiment 1 apparently does enable listeners to track words on the basis of consonants. Hence, the same is expected for the bilingual participants. The prediction is that they will even perform significantly better on the segmentation test than the monolingual participants did. Although the monolingual participants were unsuccessful at detecting the vowel pattern in the artificial language, perhaps the added experience with rule learning that the bilingual participants have will enable them to discern the ABA pattern. It is therefore still possible that the bilingual participants outperform the monolingual participants on the generalisation test.

In sum, a greater performance by the bilingual participants on the segmentation test and the generalisation test will confirm the hypothesis that bilinguals are better at statistical and rule-based learning. An equal or poorer performance on the segmentation test will refute our hypothesis, but such a performance on the generalisation test will give no definite conclusion about the hypothesis.

The prediction is that bilinguals will outperform monolinguals in a task requiring statistical and rule-based learning. More specifically, I predict that the bilingual participants will perform better than the Dutch monolingual participants both on the segmentation and the generalisation test of the forced-choice task which they will execute on the basis of 10 minutes of exposure to the artificial language. This outcome will be interpreted as supporting the hypothesis that bilinguals are better at statistical and rule-based learning than monolinguals due to added experience.

5. Experiment 3

5.1. Participants

Participants were 23 bilinguals (17 female, 6 male) with varying language combinations. For each bilingual participant one of the two native languages was Dutch and the other was either Spanish (4), English (2), Portuguese (1), Arabic (1), Kurdish (1), Moroccan Arabic (1), Turkish (1), Pashto (1), Frisian (1), Kiswahili (1) or Tamil (1). Also, of the 23 bilingual participants, 8 people were actually multilingual, that is, had more than two languages. Their native languages, beside Dutch, were German and English (1), French and English (1), French and Lingala (Congo African) (2), Farsi and Dari (1), English and Sranan Tongo (1), French, English and Sinhala (1) and English, Spanish and Papiamentu (1). Although the hypothesis specifically claims a bilingual advantage in statistical learning, multilingual participants are presumed to show the same advantage as bilinguals. Crucially, multilinguals share with bilinguals the fact that they have increased language experience as compared to monolinguals, which should therefore improve their statistical learning ability in a similar fashion. If anything, the multilingual participants could possibly outperform the bilingual participants, due to their even greater experience with statistical learning. In setting up the experiment both bilingual and multilingual speakers will be accepted for the bilingual group, and so the label ‘bilingual’ will cover both bilingual and multilingual participants. Afterwards, the results will be checked for a possible difference in performance between multilingual and bilingual speakers. Participants were consciously selected to have different native languages, as this study is looking to research a general facilitative effect of bilingualism on statistical learning as opposed to a facilitative effect caused by transfer from the non-Dutch language. The bilingual participants were all simultaneous bilinguals, according to the definition that I keep to, having been exposed to both their languages before the age of 4. People who have been exposed to a subsequent language after the age of 3 are considered second language learners, and were excluded from participation. I verified the simultaneous bilingual status of the participants by asking for the age of exposure to all their native languages in a questionnaire (see appendix B).

The bilingual participants were recruited in several ways. First, by contacting organisations which are associated with bilingualism, such as expatriate organisations, cultural societies and international student organisations, via email and, when present, posting requests for bilingual participants on their forums. A list of these and the corresponding contact information were collected from the internet. Second, by contacting students and acquaintances from my personal network via email, and finally by posting similar requests in several university buildings in Utrecht, both in the city centre and at de Uithof. All participants received 5 euro for their participation.

As with the monolingual groups, participants' age ranged between 18 and 26. However, several exceptions were made. Bilinguals participated who were 15, 16(2), 30(3) and 40 years old. These exceptions were made because it was considered more valuable to have a larger group of bilingual participants than to keep strictly to the age boundaries set for the monolingual participants. If anything, the older participants can be expected to perform worse than the bilingual participants who were within the 18 to 26 year age range due to the onset of a decline in cognitive functions. Thus, the decision to include these 3 participants can only possibly hinder achievement of the hypothesised result. The minimal age for participation in the experiment was set at 18 because at this age, both females and males have completed puberty (Lee, 1980: abstract). As for language learning, however, at age 14 the brain is already developed (Moore & ten Bosch, 2009: 3) and vocabulary size remains more or less stable (Giedd et al., 1999: 861). Therefore, even the youngest participants of 15 and 16 years can be expected to perform on the forced-choice task in the same way as adults within the predetermined age range. The average age of the bilingual participants was 23.0.

5.2. Stimuli

The same stimuli were used as in experiment 1.

5.3. Task and Procedure

Task and procedure were identical to those in experiment 1. One exception was that participants received a different questionnaire than the monolingual participants in experiment 1 and 2 did. In addition to the questions in this questionnaire, the bilingual participants were also asked for some personal information, such as their age and if they had any hearing problems. Also, they were asked questions about their native languages, for instance at what age they came into contact with them and how often they use them. The questionnaire is presented in appendix B.

5.4. Results and Discussion

Participants did not exhibit a preference for rule-words over nonrule-words (M = 50.5%, ± 5.0, $t(22) = 0.15$, $p > 0.05$ (0.88)). Apparently, the bilingual participants were unable to detect the ABA vowel pattern in the artificial speech stream, just like the monolingual participants. The bilingual participants did score significantly above chance on the segmentation test (M = 59.8%, ± 4.9, $t(22) = 2.70$, $p < 0.05$ (0.01)). Participants therefore had a preference for words over part-words. However, the bilinguals' score on the segmentation test proved not to be significantly higher than the monolinguals' score ($p > 0.05$ (0.52)). The bilingual participants did not perform significantly above chance on the generalisation test (M = 50.5%, ± 5.0, $t(22) = 0.01$, $p > 0.05$ (0.883)).

First, these results show that both groups of participants were able to derive words which could be learned with their statistical learning ability from the artificial language. However, the results also indicate that the bilingual participants were not significantly better at either statistical learning or rule-based learning than the monolingual participants in this study. This null result cannot reasonably be ascribed to phonological or lexical interference. As for the influence of L1 phonology, there should be no strong effect of the other native language, as the participants have varying language combinations. Thus, any facilitative or restrictive effects that the bilinguals' second native language might have on their performance in the forced-choice task should even each other out. For the same reason, namely a large variety of different language combinations, there should not be an effect of lexicon of the second native language.

Some additional remarks deserve to be made about the bilingual's statistical learning ability. In the bilingual group no distinction was made between actual bilinguals, persons with two native languages, and multilinguals. The latter term is here defined as persons with more than two native languages, as opposed to the conventional definition of a person with two or more languages, therefore encompassing bilingual speakers as well. When distinguishing between actual bilinguals and multilingual, a trend also emerged for multilinguals to perform better on the statistical learning task than the bilinguals (M = 63.6%, ± 4.9 versus M = 58.1%, ± 5.0). Therefore, there seems to be an upward trend when it comes to the number of native languages, with bilinguals performing slightly better than monolinguals and multilinguals performing slightly better than bilinguals. Crucially, because the interaction was not statistically significant ($p = 0.725$) I can only speak of trends. The bilingual participants did not score significantly better on the segmentation test than the monolingual participants ($p = 0.433$) and the multilingual participants did not perform significantly better than the bilingual participants ($p = 0.638$)

I further looked at a possible correlation with age of exposure, comparing bilingual participants who were exposed to at least two native languages from birth (n = 17) with bilinguals who were only exposed to one of their native languages from birth and the other(s) later, at either age 1, 2 or 3 (n = 6). After all, it might be that there is only a statistical learning advantage for bilinguals who have had to segment two languages from birth, or perhaps that there is a greater advantage for those bilinguals compared to bilinguals who have only been exposed to one language from birth. No difference emerged from this comparison: those bilinguals who are bilingual from birth scored no better (M = 60.3%, ± 3.6) on the segmentation task than the rest of the bilinguals (M = 58.3%, ± 4.3).

Furthermore, the effect of fluency and regular use of the bilinguals' native languages on performance was checked. It was not expected however that these two factors would be of influence on the bilinguals' performance, since according to the hypothesis, anyone who has been exposed to two languages from a young age should have the extra experience in statistical learning to facilitate a statistical learning task. It was difficult to determine the value of these two factors from the questionnaires. Participants were asked to give an estimate of how often they use their native languages and to indicate whether one of their languages is dominant in certain areas, for instance speaking, writing, listening or reading. The information given by the participants was sometimes not sufficient to determine the use of, and especially the fluency in, both or all languages. Yet an attempt was made to distinguish participants on the basis of these two factors, with participants grouped as either 'actively bilingual' or 'passively bilingual'. However, scores did not, as was expected, differ for participants in the two groups.

Finally, consideration was given to whether the bilinguals' other native language(s), beside Dutch, might have had an influence on their segmentation. This factor was anticipated to have no significant effect on the participants' performance because bilingual participants were consciously chosen with varying native languages. However, although there may not have been an effect of language, there is a chance that there was an effect of type of language. Recall that the artificial language is more like a syllable-timed language, like Italian, in terms of phonological structure than like a stress-timed language, like Dutch. Therefore, participants with a native language that is also syllable-timed might have an advantage over participants with a stress-timed language, as the former might facilitate correct segmentation of the artificial language. Bilinguals were therefore divided into two groups: one containing those participants who have at least one syllable-timed language among their native languages and one containing those who have only stress-timed languages. Although there were some differences (syllable-timed native language: M = 56.9%, ± 2.5; stress-timed native language: M = 54.2%, ± 1.4), type of language proved to have no significant effect on performance on the forced-choice task ($p = 1.93$).

As regards rule-based learning, for whatever reason none of the participant groups were able to detect the ABA vowel pattern in the artificial speech stream. Since this study duplicates the design by Toro et al. and they did in fact find a positive result for their monolingual participants in the rule-based learning part, there must be some reason why I failed to match these results. Many things can lead to failure in attempts to replicate the results of existing studies, primarily because exact replication can never be possible. First, the experimental setting will inevitably be different, for example contact with the participants and exact words of instruction. In addition, a replication will not test the same participants as were tested in the original study. In association with this, no one participant will perform exactly the same at each time of testing. Although any measurement of significance should account for such variability, there is always the possibility that a group of participants performs generally badly, or generally well. In the case of this experiment, two other factors could have led to the failure of replication. First, a change in the stimuli caused by replacing [o] with [u] could have affected the participants' performance. Second, participants' different native languages, Dutch versus Italian, could have had an influence on how the artificial speech stream was segmented.

Because the monolinguals were not able to score significantly above chance on the generalisation test, the bilinguals' score cannot give a definite answer to our research question as for rule-based learning. Of course there is the possibility that the bilingual participants are simply no better than the monolingual participants at rule-based learning. After all, they did not outperform the monolinguals in the generalisation test. However, because the monolingual group was not able to detect the pattern at all, there is the possibility that the bilingual group does have increased rule-based learning ability, yet even with this increased ability were not able to discern the vowel pattern. The pattern could have simply been too difficult to detect, no matter how great the amount of extra rule-based learning experience. The only thing that is certain is that the present results do not support the hypothesis. Results of the multilingual participants seem to reinforce this, since mean score on the generalisation test did not improve with an increased number of native languages, as was the case for the segmentation test. The trend as witnessed for statistical learning ability, namely that the more experience learners have, the more they increase their statistical learning ability, is not visible in rule-based learning ability.

In sum, based on the results of this experiment compared with the results of experiment 1, it cannot be claimed that the bilingual participants have in any way outperformed the monolingual participants. Therefore, this study has not shown evidence in favour of the hypothesis, as the bilingual participants have not been proven to perform significantly better than the monolingual participants on either a statistical learning or a rule-based learning task. I can merely speak of a trend towards increased statistical learning ability for bilingual participants as opposed to monolingual participants, as well for multilingual participants as opposed to actual bilingual speakers.

6. General Discussion

6.1. A Bilingual Advantage in Lexical Learning

In discussing the relationship between input and intake in bilingual children, Pearson et al. (1997) write: “There are several possible reasons why lowered input might not necessarily result in a direct, proportional reduction in the number of words learned. Perhaps children who are learning from reduced input are somehow more efficient at "intake", actually internalizing information, than children with more input; that is, they can derive equal benefit from less exposure.” (53). Although this suggestion is as of yet only endorsed by plain logical thinking, the idea is something worth investigating so that the ‘somehow’ in these words can be more clearly defined and explained.

This study sought to make a start at concretising the line of thought expressed by Pearson et al. Bilingual infants faced with the task of learning two languages at the same time while monolinguals infants only need to learn one, clearly have a need to complete this assignment. In the most common situation, two parents/two languages, an infant will want to understand and communicate with both parents just as monolingually raised infants do, only the latter have the convenience that both parents speak the same language. Besides, in the earliest stages of language acquisition, bilingual infants cannot even distinguish between the two languages (Goodz, 1989) and thus the learning of two languages commences unconsciously. In sum, bilingual infants have no choice but to acquire two languages where a monolingual infants needs to learn only one.

There are then three potential scenarios for the rate of linguistic development of a bilingual child. The two most logical possibilities are that the child either develops at the exact same rate as a normally developing monolingual child would, or it develops more slowly. The third and final possibility is what seems to be true for lexical learning, namely that progress in acquisition by bilingual children differs from monolingual children because acquisition rate can be both faster and slower at different points in time. Specifically, in lexical development, bilingual children seem to start off slowly and eventually catch up with their monolingual counterparts. In saying this, it has to be emphasised that these developmental rates are developmental rates for a single language. When considering lexical development as a combination of the vocabulary for two languages, bilinguals never in their lifetime lag behind monolinguals, but only ever equal or surpass them. All adult bilinguals have a total vocabulary larger than that of a monolingual, and sometimes even twice as large. In fact, bilingual children seem to surpass their monolingual counterparts already at a young age (Nicoladis, 2003; qtd. in Nicoladis, 2008: 170). It seems therefore that bilinguals are learning more than monolinguals in the same period of time.

Adopting a theory of lexical acquisition in which implicit learning is considered the primary means for language acquisition, one straightforward explanation for why bilinguals are able to learn more words in the same amount of time as monolinguals is that their implicit learning skills have somehow become greater. The observation made by Pearson et al. that bilinguals might somehow be more efficient at intake, can be explained by a language acquisition theory based on statistical and rule-based learning. If statistical and rule-based learning ability, in combination with among other things phonotactic, phonetic and prosodic cues, attention and memory, are the driving forces behind lexical learning, these skills might be expected to somehow be improved for bilingual children. However, there is still the question of how exactly this could happen.

This study gives some careful indications as to how exactly bilingualism can affect implicit learning. The bilinguals in this study did not prove significantly more successful at a statistical learning task, nor at a rule-based learning task. A positive result would have indicated an even greater advantage for bilingually raised people than previously thought. This outcome suggests that there is no bilingual advantage for statistical or rule-based learning. The findings in this study do suggest that there is the possibility that different results can be obtained in further research. In order to obtain either a definite confirmation or rejection of the hypothesis, more carefully designed research is needed.

6.2. Concluding remarks

As regards statistical learning, bilinguals did not perform significantly better than monolinguals on a statistical learning task, which they should have if the extra experience that they have with statistical learning improves statistical learning ability. This study does not provide proof, therefore, that bilinguals' extra experience due to a greater and more complex lexical learning task improves their statistical learning skill. There is however a trend towards greater performance on the statistical learning task by bilinguals. This trend does indicate that with additional research the hypothesised result could possibly be obtained.

This suggestion is further strengthened by the observation that, when a distinction is made between bilinguals and multilinguals, there was also a trend visible for multilinguals to perform better on the statistical learning task than the bilinguals. Therefore, there seems to be an upward trend when it comes to the number of native languages: bilinguals perform a little bit better than monolinguals, and multilinguals also perform slightly better than bilinguals. Of course, none of these results were statistically significant and I can therefore only speak of trends. However, when looking at the total picture, the results do seem cautiously promising and perhaps further research could obtain different results. As it is, this study can be much improved in terms of experimental design, namely a greater sample size, stricter participant selection and a better experimental set-up, which would result in a more reliable outcome. Several other factors which could have possibly had an effect on the bilingual participants performance on the segmentation test were considered, namely age of exposure to the native languages, fluency and use of the native languages, and the type of the participants' native languages (syllable-timed or stress-timed). Neither of these factors revealed to have a significant interaction with the bilinguals' statistical learning ability/performance.

All in all, the results of this study for rule-based learning do not confirm the hypothesis. Bilinguals did not outperform monolinguals in a statistical learning task and so bilinguals did not demonstrate increased statistical learning ability due to extra experience. However, the results do not exclude that such a result could be obtained when important factors such as sample size and participant selection are improved. There is, namely, a trend towards greater statistical learning ability in bilinguals as compared to monolinguals. Also, there is a trend towards statistical learning ability continuously improving with increasing experience, such that multilinguals outperform bilinguals, although not significantly so.

As regards rule-based learning, none of the participant groups were able to detect the ABA vowel pattern in the artificial speech stream. The design of the artificial language seems not to allow any type of participant to deduce the vowel pattern from it after 10 minutes of exposure. Therefore, a comparison between the monolingual and bilingual participants is not completely reliable. The bilingual participants could have outperformed the monolingual participants, which would of course have supported the hypothesis, but it is also possible that the rule-based learning task was too hard in general, so that even an increased rule-based learning ability does not enable above chance performance.

In any case, the results on rule-based learning in this study cannot be taken as evidence against the hypothesis. Besides the apparent imperceptibility of the vowel pattern, possibly preventing the bilinguals from demonstrating their hypothesised superiority over the monolinguals, the scale of this study also prevents the drawing of definite conclusions.

In sum, neither monolinguals nor bilinguals were able to use rule-based learning to detect a vowel pattern from artificial speech, and therefore no conclusion can be drawn about the rule-based learning ability of bilinguals as compared to monolinguals. This study does support previous research (e.g. Saffran et al., 1996; Saffran et al., 1997) demonstrating that normally developing adults are capable of statistical learning, i.e. to learn novel words from a novel language by calculating the transitional probabilities between consonants. However, this thesis was not able to prove that statistical learning ability is better developed in bilinguals than it is in monolinguals. Therefore, the outcome of this study does not provide evidence for the hypothesis that bilinguals have increased statistical and rule-based learning ability as compared to monolinguals, due to added experience from the increased quantity and complexity of their input.

6.3. Future Research

I cannot stress enough that the scale of this research is not nearly large enough to attach any certainty to its outcome. Besides dealing with a small sample size in each of the three experiments, participant selection for the bilingual group was not as strict as would have been ideal. Even though individual scores do not seem to reinforce this, deviations from the optimal age for cognitive processing could have influenced participants' performance. At the very least, it makes the findings less reliable. Also, to increase the sample size of experiment 3, age 3 was chosen as the maximum age of exposure to the bilinguals' second native language. Preferably though, only bilinguals should have participated who were exposed to both native languages from birth. These bilinguals are simultaneous bilinguals in the strictest sense, since they have always had input from the two languages together. It is possible that bilingual learners with an age of exposure higher than zero for their second native language do not experience all the benefits that simultaneous bilinguals as defined by the strict definition do. Since segmentation of input is realised from birth on, it is possible that by age 2 or 3, the need for statistical and rule-based learning is highly reduced or may even be entirely gone, as infants have already segmented the input of their language(s). Although this is possible, it is unlikely since adults are still capable of statistical and rule-based learning, even equally well as infants (e.g. Saffran, Newport, Aslin, Tunick & Barrueco, 1997; Saffran, J. R., Newport, E. L., & Aslin, R. N., 1996). In any case, because implicit learning is used to segment speech from birth, bilinguals exposed to both languages from birth have more experience with statistical and rule-based learning than bilinguals with a higher age of exposure for one of the languages. Thus, if there is any effect of bilingualism on statistical and rule-based learning ability, it might only be large enough to be perceived by the former group and not by the latter. Also, presuming that an infant is able to perceive the input as belonging to two different languages at age 2 (Fraser Gupta, 2010: screen 8), the claim that statistical and rule-based learning would be a more complex task cannot be made about infants at this or a later age of exposure. Therefore, testing only simultaneous bilinguals in the strictest sense, bilingual from birth, might potentially reveal the hypothesised effect. Another confounding effect in this study is of course that I was not able to devise an artificial language which tests for rule-based learning. Undoubtedly, given more time, an artificial language could have been designed from which a monolingual control group could discern both the statistical relations and the rule. Rule-based learning could for instance have been achieved with an artificial language with even less or possibly even no filler syllables, or by lengthening the duration of the present artificial speech stream. Unfortunately, the scale of this Master's thesis did not allow for additional testing, just as it forced me to maintain a less strict selection of the participants than would have been ideal.

The task for future studies lies first and foremost in testing statistical and rule-based learning with a larger sample size. Also, bilingual participants should only be tested on an artificial language which proves to be a good test of statistical and rule-based learning as manifested by a monolingual control group. Moreover, criteria for selection of the bilingual participants should be clearly defined and adhered to without exception. The age of participants should always be between 18 and 26, and all participants should have been exposed to both languages from birth. Also, initial research should attempt to have only bilingual participants and no multilingual participants, as these might perform differently from bilingual learners and therefore affect the results. Furthermore, future research might investigate only bilinguals with the same second language instead of bilinguals with different language combinations. In this way, phonological and lexical effects of both native languages can be controlled for.

If future studies do find that bilingualism increases statistical and rule-based learning ability, this would raise some other interesting questions as to the exact nature of the bilingual advantage. First, does increased experience due to bilingualism have the same impact on statistical and rule-based learning or are these two skills affected in different ways? Is the resulting advantage for both skills identical, or is one increased more than the other? A second possibility for research concerns the age of exposure. What role does age of exposure to both native languages play in the bilingual advantage? Is there only a bilingual advantage when two or more languages are acquired from birth or might a later age of exposure still enable increased statistical and rule-based learning ability? If the latter is the case, is there a clear cut-off age until which the advantage can be obtained or does increasing age of exposure result in gradually less improvement in statistical and rule-based learning skill. Finally, a very fruitful area for research seems to concern the role that multilingualism plays in statistical and rule-based learning. Additional research would have to confirm that with each additional native language, a learner's statistical and rule-based learning ability increases.

In sum, this study does not confirm the hypothesis, but neither does it give reason to refute the hypothesis completely. Future research should test the hypothesis on larger groups of participants, improve the experimental design and maintain strict criteria for participant selection, to enable the obtainment of a definite conclusion. For now, there is no support for the hypothesis that bilinguals are better statistical and rule-based learners.

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Appendix

APPENDIX A: *Questionnaire for the monolingual participants*

Instruction: Please answer the following questions truthfully. There are 9 questions in total. Do not forget to answer the questions on the back.

1. Did you find the experiment hard or reasonable?
2. Did you have a strategy when listening (to distract words from the language)? If so, what was this strategy?
3. Did you recognise any Dutch words in the language? If so, which ones (that you can remember)?
4. Did you recognise words from other languages? If so, which ones?
5. Do you speak any other languages beside your native language?
6. Where do you use this/these language(s)? E.g. at work/school, with friend/family members etc.
7. How often do you use this/these language(s)? Give an indication.
8. Did you ever take any specific language courses? If so, what kind of course(s) and for how long?
9. Have you ever been exposed to other foreign languages? (E.g. Have you spend any length of time abroad, several weeks/months.)

APPENDIX B: *Questionnaire for the bilingual participants*

Instruction: Please answer the following questions truthfully. There are 18 questions in total. Do not forget to answer the questions on the back.

1. Are you male/female?
2. What is your date of birth?
3. Do you have any hearing problems?
4. Do you have dyslexia?
5. Did you find the experiment hard or reasonable?
6. Did you have a strategy when listening (to distract words from the language)? If so, what was this strategy?
7. Did you recognise any Dutch words in the language? If so, which ones (that you can remember)?
8. Did you recognise words from other languages? If so, which ones?
9. What are your native languages? Write down only those languages that came in contact with before the age of 3.
10. At what age did you come in contact with each of the languages just listed? Write down the age for each language separately.
11. Where do you use your native languages? (E.g. with certain family members or in certain situations.)
12. How often do you use your native languages? Give an indication.
13. Is one of your native languages, in your opinion, more dominant than the other(s)? If so, in which area(s)? (E.g. speaking, reading, writing, listening.)
14. Do you speak any other languages beside your native languages?
15. Where do you use this/these language(s)? E.g. at work/school, with friend/family members etc.
16. How often do you use this/these language(s)? Give an indication.
17. Did you ever take any specific language courses? If so, what kind of course(s) and for how long?
18. Have you ever been exposed to other foreign languages? (E.g. Have you spend any length of time abroad, several weeks/months.)