The acquisition of morphophonological alternations across languages

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by

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1

Introduction

Infants appear to acquire their native language quickly and easily, becoming competent communicators in a short space of time. However, becoming proficient in a language is a remarkable feat involving a multitude of complex processes. One such process is identifying the phonemes of the language, phonemes being contrastive sounds that tend to signal a change of meaning (Cruttenden, 2001). The learner is faced with the task of identifying, for example, that /s/ and /z/ are phonemes of English; the words *sip* and *zip* have different meanings because of the difference between the initial sounds. /s/ and /z/ are in fact remarkably similar sounds, they share place (alveolar) and manner (fricative) features, and differ only in voicing (the presence or absence of vocal-fold vibration). Alongside identifying phonemes, infants also need to identify words and word-boundaries - speech does not contain spaces between words as written text does - and form links between sequences of sounds and meaning. Words are not uttered in isolation; language is made up of complex utterances and words are ordered in a systematic and meaningful way. When words are concatenated into phrases or sentences inflectional morphology is required to make the utterance grammatical (cf. **she have two book* vs. *she ha<u>s</u> two book<u>s</u>*). Children need to learn that adding grammatical, or inflectional, morphemes only minimally alters semantic meaning; both *book* and *books* refer to the same object but differ in whether one or more than one are being referred to.

Inflectional morphology is not an isolated process; it is not simply a matter of ordering morphemes like beads on a string. Concatenating morphemes can trigger changes in the phonological form of a word. Take the English plural suffix as an example. Many speakers will have little difficulty in identifying the plural suffix as *-s*, but in speech there are three variants of this morpheme, selected on the basis of properties of the preceding segment: following a voiceless obstruent it will be pronounced [s] (e.g. *books*), following a voiced segment [z] (e.g. *dogs*), or following another *-s* [ɪz] (e.g. *glasses*). Note the conflicting information that the learner must reconcile; /s/ and /z/ are semantically contrastive and therefore phonemes, but the plural suffix makes use of the same acoustic contrast without the semantic contrast. In this example it is the acoustic form of the affix that alternates. The word-form *books* contains the stem *book* in its entirety, in the same way that *dogs* contains the stem *dog*. There are also examples of changes to the stem itself. Consider the English word *knives*, with a medial [v], which neither orthographically nor phonologically contains the stem *knife* with [f]. Similar alternations occur in English that are not reflected in the spelling, for example the stem-final [s] of *house* in the plural will be voiced: [haʊzɪz].

Stem alternations, such as the *knife-knives* case, are reasonably rare in English. The rule is clear and rather easy to learn because it applies predominantly to words ending in fricatives. A similar voicing alternation is found in both Dutch and German, but is not restricted to one manner of articulation and the system is less transparent. Stem-final voiceless obstruents (/p,t,k,f,s,x/) may alternate with their voiced counterpart (/b,d,g,v,z,ɣ/) in a complex word form. For example the Dutch word *bed* (‘bed’) is pronounced with a final [t] - [bɛt] - but the plural is *bedden* [bɛdən], with a [d]. Not all words contain an alternation; the word *pet* (‘cap’) contains a [t] in both the singular and plural forms: [pɛt]~[pɛtən]. The complicating factor in Dutch and German is that *all* obstruents in final position are pronounced voicelessly because of a phonotactic constraint against voiced obstruents in this position. Hearing the words [bɛt] and [pɛt] the learner has no information as to which form has an alternation in the paradigm and which does not. This information only becomes apparent once multiple members of the morphological paradigm are encountered; once they have heard both [bɛt] and [bɛdən]. The constraint against voicing in final position is not restricted to nouns; any obstruent in final position will be voiceless regardless of word class. Verbs and adjectives are inflected for case, number or gender agreement in German and Dutch with vowel initial suffixes, and alternations occur in these morphological paradigms too. For example the Dutch verb *raden* ‘to guess’ appears with a final [t] in *ik raad* [raːt] (‘I guess’), but a medial [d] in *wij raden* [raːdən] (‘we guess’). Note that although the orthography is transparent (*raad* and *raden* are written with a *d*), the child is learning from the spoken form and does not have access to orthographic information.

The question forming the core of this thesis is: How do Dutch and German children acquire morphophonological stem alternations? The focus is on the voicing alternation in singular-plural pairs, with experiments conducted at two points of development. Chapter 2 investigates pre-verbal infants' sensitivity to voicing alternations. At nine months old infants have language-specific listening abilities, for example they will have learned that both voiced and voiceless obstruents occur in their native language. This chapter investigates whether infants show early sensitivity to statistical properties of inflectional morphology, and whether or not they can suspend their knowledge of the contrastiveness of voicing in this context. Chapters 3 and 4 consider 3-year-olds' knowledge of voicing alternations in familiar words. By three years old children are reasonably competent language users with quite a sizable vocabulary. In addition they can produce grammatically complex utterances, though not always accurately. Chapter 3 investigates the effects of language specific factors on the acquisition of voicing alternations, and Chapter 4 considers differences between children's production and perception of voicing alternations and the role of phonological context.

German and Dutch are two closely related languages, both West Germanic and both spoken predominantly in Western Europe. The languages themselves are not only very similar, but the culture and society in which infants are being brought up also bear many similarities. Despite these similarities, and the fact that both languages have a similar pattern of voicing alternations, there are differences between the two. By comparing the acquisition of the same feature cross-linguistically this thesis aims to address the relative contribution of language-specific factors and more general cognitive or developmental factors. Chapters 2 and 3 investigate whether the acquisition of voicing alternations progresses in the same manner and at the same pace for learners of Dutch and German, or whether there are language-specific factors that assist one group more than the other.

There are a number of issues that return throughout the thesis which will be addressed here: How, and when, do children acquire morphology? How are morphophonological alternations acquired? How are morphologically complex words represented in the mental lexicon? How do the Dutch and German differ?

1. How do children acquire morphology?

The acquisition of morphology by children has received much attention in the literature. The classic approach to studying language acquisition was for parents to keep a diary of their child's speech, noting down what their child said, and when. These notes would later be examined, for example to identify the age-of-acquisition or developmental course of specific linguistic features (Brown, 1973; Clark, 1973; Goldfield & Reznick, 1990; Inkelas & Rose, 2007; Mervis & Johnson, 1991; van Ginneken, 1922; Velten, 1943). In an early example of such a study Van Ginneken (1922) described the language development of a Dutch toddler, based on detailed notes from the child's mother. More recently, Mervis and Johnson (1991) used a diary study to investigate the acquisition of the plural morpheme by one child from 18-months-old to 30-months-old. Recording children's speech is an alternative method of collecting longitudinal data, and one that is becoming increasingly more accessible. Recordings remove the reliance on parents' interpretation of their child's behaviour, and also provide a record of the child's complete auditory environment, including the speech of the parents or caregivers. Cazden (1968), for example, followed the acquisition of noun and verb inflections by Adam, Eve and Sarah, three children who had participated in Brown's (1973) study. Data were based on tape recordings made weekly or bi-weekly in the children's homes. Recent technological developments such as the recording device and software for automated speech analyses of the LENA Research Foundation (For technical details see Ford, Baer, Xu, Yapanel, & Gray, 2008), or the PhonBank Project (Burkinshaw, Hedlund, Knee, Peddle, & Rose, 2013) make large-scale, detailed analyses of children's productions possible.

An alternative to longitudinal studies is cross-sectional experimental studies. Whereas longitudinal studies can focus on developmental patterns, experimental studies provide a detailed, cross-sectional view of a grammatical feature at a given age. As such, group-level patterns can be measured rather than focusing on one child or a small sample of children. In addition, observational studies are by nature descriptive, they measure what the child says and when, but not necessarily what they know or the processes involved. One of the earliest experimental studies into children's morphological acquisition (Berko, 1958) looked at children's ability to generalise morphological rules to novel forms, and whether they could use the correct allomorph. Using the (by now infamous) "wug-test" children between the ages of 4 and 7 were asked to provide the inflected form of a novel word, for example the plural of a novel noun or the past tense of a novel verb (see Fig. 1). In doing so children provided insight into their knowledge of morphological processes, rather than their knowledge of specific forms. If a child correctly says *two cats* and *two dogs* it is not possible to deduce whether they have memorised that the plural of *cat* is *cats* and the plural of *dog* is *dogs,* or they know that the plural is formed by suffixing [s] or [z] to the stem form, and the choice of which depends on the voicing of stem-final segment. If they correctly say that the plural of *wug* is *wugs* they must have a productive rule for plural formation because they have never encountered this form before.

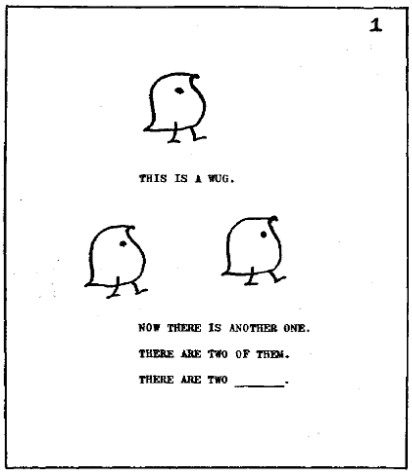

Figure 1. Sample materials from the wug-test (Berko, 1958, p. 154).

Much attention has been given to the acquisition of irregular morphological forms compared to regular forms. For example, it is easy to imagine a rule or generalisation that states that the plural in English is formed by suffixing *-s* to a stem, or the past tense by suffixing *-ed* (e.g. *walk-walked*); these forms are regular. It is more difficult to imagine a rule that mediates between the singular *child* and the plural *children*, or the present tense *go* and the past tense *went.* An error such as **childs* or **goed* is an overregularisation or overgeneralisation. The typical developmental pattern described is a U-shaped curve, which Cazden (1968) broke down into four stages. In the initial phase children's speech contains no inflectional marking. During the second phase inflectional morphology will be used occasionally and accurately, with no errors or overgeneralisations. The third stage is characterised by an increase in productions and the appearance of errors and overgeneralisations, and at the final stage children have mastered the system meeting the criteria of 90% correct use (Cazden, 1968, p. 436). Dressler and Karpf (1994) argue that the transition from the second to third phase reflects a transition between pre- and protomorphology. During the premorphological phase some complex words are used, but they are rote-learned. Children repeat words that they have heard without the ability to analyse them for morphological complexity because, it is argued, morphology as a sub-system of the grammar has not yet separated itself from the general lexicon. Protomorphology corresponds to the third stage of Cazden's (1968) description. At this point morphology as a subsystem is starting to develop, and children have the ability to be productive and creative in their use of morphology, sometimes resulting in overgeneralisations. The protomorphological phase ends when the morphological system continues beyond the early stages and sub-divides into inflectional, derivational and compounding systems (Bittner & Köpke, 2001; Dressler & Karpf, 1994).

This thesis focuses on the acquisition of noun plurals. Alongside the ability to use and comprehend grammatical number children must also develop the cognitive ability to distinguish between 'one' and 'more than one', an ability that appears to be in place by around the second birthday. Coincidentally this is about the same age that (English-learning) children start comprehending (Kouider, Halberda, Wood, & Carey, 2006; Wood, Kouider, & Carey, 2009) and producing (cf. Cazden, 1968; Mervis & Johnson, 1991) morphological plurals. It has been debated which comes first (Barner, Thalwitz, Wood, Yang, & Carey, 2007); does linguistic distinctiveness support the development of conceptual distinction, or vice versa? Further studies have found that Mandarin Chinese and Japanese are also able to distinguish one from many by 24-months-old, despite not yet comprehending linguistic markers of singular and plural in their native language (Li, Ogura, Barner, Yang, & Carey, 2009).

Chapter 2 of this thesis looks at sensitivity to the phonological and statistical properties of plural markers by 9-months-old. Such young infants are referred to as "preverbal" in the literature; they do not yet use language themselves[1], though their perceptual system is fast becoming specialised to the patterns of their native language (see Cutler, 2012, Chapter 8 for overview). Recent literature has focussed on infants' abilities to extract information purely from the statistical distribution of cues in the input. In one of the first studies to show infants as statistical learners, Saffran, Aslin, & Newport (1996) found that if infants are exposed to strings of nonsense syllables, they are able to use the transitional properties - the frequency that one syllable occurs after another - to identify "words". This line of research has been extended in recent years by Shi and colleagues to investigate infants' sensitivity to morphological properties of the input (Marquis & Shi, 2008; Shi & Cyr, 2008; Shi & Marquis, 2009). In these studies they found that infants are sensitive to the distribution and frequency of inflectional affixes, for example that inflectional affixes are highly frequent and can occur in any number of phonological contexts. Marquis and Shi (2012) also claimed that infants are sensitive to the fact that inflectional affixes do not alter the core semantic meaning of the word. In Chapter 2 it is tested whether this conclusion holds for Dutch- and German-learners, and whether their sensitivity extends to include voicing alternations.

1.1 Plurals in Dutch child-language

In Dutch there are two productive plural suffixes, *-en* and *-s,* and the choice between them is predominantly phonologically determined. Numerous descriptive accounts (cf. Haeseryn, Romijn, Geerts, de Rooij, & van den Toorn, 1997; Van Haeringen, 1947; Van Wijk, 2002, 2007; Zonneveld, 2004) identify three phonological conditions that determine the choice of allomorph; one rhythmic and two segmental (see Table 1). In terms of rhythm, *-en* follows a stressed syllable and *-s* an unstressed syllable. However, if the stem is vowel-final there is a preference for *–s*. Additionally, if a stem ends in a sibilant, there is a preference for *–en*. There are also two non-productive irregular formations. The

[1] With the exception of babbles, which are also taking on language specific properties (e.g. de Boysson-Bardies & Vihman, 1991; Levitt & Wang, 1991; Whalen, Levitt, & Wang, 1991). Note this age group has also been referred to as "prelinguistic", but in light of evidence that they do engage in linguistic processing, "preverbal" is a more appropriate term.

first group are loan words that have retained inflectional properties of the original language, the second group use the suffix *-en* with an additional change such as an epenthetic vowel or stem-vowel change (Zonneveld, 2004, p.3).

Table 1
Plural formation in Dutch.

	Suffix	*Singular*	*Plural*	
a.i.	*-en*	*paard*	*paarden*	'horse(s)'
		konijn	*konijnen*	'rabbit(s)'
		rivier	*rivieren*	'river(s)'
a.ii.		*vis*	*vissen*	'fish'
		harnas	*harnassen*	'armour'
		albatros	*albatrossen*	'albatrosses'
b.i.	*-s*	*lepel*	*lepels*	'spoon(s)'
		robot	*robots*	'robot(s)'
		lexicon	*lexicons*	'lexicon(s)'
b.ii.		*ski*	*ski's*	'skis'
		avocado	*avocado's*	'avocados'
		café	*café's*	'cafes'
c.i		*promovendus*	*promovendi*	'PhD student(s)'
		museum	*musea*	'museum(s)'
		lemma	*lemmata*	'lemma(s)'
c.ii.		*koe*	*koeien*	'cow(s)'
		kind	*kinderen*	'child(ren)'
		schip	*schepen*	'ship(s)'

The acquisition of the plural in Dutch is described in detail by Schaerlaekens (1977), Van Wijk (2007) and Zonneveld (2004). All agree that regular plural morphology will initially appear in children's speech between 18 months and 2 years of age, and be used correctly, with correct selection of allomorph, approximately a year later. Markers of plurality may appear earlier in the child's speech, but are more likely to be marked syntactically rather than morphologically, for example using the numeral *twee* ('two'), the phrase *nog een* ('another'), or *allemaal* ('all' / 'all together'). In addition, if the incorrect allomorph is selected, it is more likely to be overapplication of *-s* than *-en.* Errors in irregular plural forms remain until 4-6 years of age.

Table 2

Examples of errors in Dutch children's plural productions (Schaerlaekens, 1977).

Child's production	Age	
Nog bal, nog bal, en nog een bal	1;11	'other ball, other ball, and another ball'
allemaal twee schoen	2;1	'altogether two shoe'
allemaal twee auto's	2;8	'altogether two cars'
visses, schoenes	2;8	'fishes' and 'shoes'

1.2 Plurals in German child-language

In German the plural is formed by the suffixes *-(e)n, -e, -er, -s.* In addition, some nouns take no overt suffix for plurality, and may require umlauting of the stem vowel. The suffixes *-e* and *-er* may also be combined with umlauting. The choice of allomorph is somewhat dependent on phonological, lexical and semantic properties of the noun (Wurzel, 1994), however there are so many exceptions that it has also been claimed that the choice is somewhat arbitrary (Marcus, Brinkmann, Clahsen, Wiese, & Pinker, 1995). Even though some patterns and regularities can be found, there are many exceptions to each. One attempt to generalise the pattern (Mugdan, 1977, cited in Marcus, 1995) comprised a list of ten rules and fifteen lists of exceptions. Bearing the high number of exceptions in mind, the following patterns can be noted (Marcus et al., 1995; Szagun, 2001): most masculine and neuter nouns take *-e¸* or *-er.* Feminine nouns never take *-er.* If the stem is masculine or neuter and ends in *-er, -el, -en, -chen* or *-lein*, it will not receive an overt plural suffix. *-s* has been referred to as the default suffix (Clahsen, 1999; Marcus et al., 1995), despite its low frequency, because it is the plural suffix for nouns that end in an unstressed vowel (not schwa), as well as names, loan words, borrowings, acronyms, truncations or onomatopoeic nouns. Exact counts of how many nouns take each suffix vary, and Szagun (2001) provided the following overview: *-n* 53-68%, *-e* 22-33%, *-er/-s* 2-8%.

Table 3
Plural formation in German (Szagun, 2001).

Suffix	*Singular*	*Plural*	
-(e)n	*Blume* (fem.)	*Blume-n*	‘flowers’
	Bär (masc.)	*Bär-en*	‘bears’
-e	*Hund* (masc.)	*Hund-e*	‘dogs’
Umlaut + *-e*	*Baum* (masc.)	*Bäum-e*	‘trees’
-er	*Kind* (neut.)	*Kind-er*	‘children’
Umlaut + *-er*	*Buch* (neut.)	*Büch-er*	‘books’
- ø	*Tiger* (masc.)	*Tiger*	‘tigers’
Umlaut + *-ø*	*Mutter* (fem.)	*Mütter*	‘mothers’
-s	*Auto* (neut.)	*Autos*	‘cars’

One study looked in detail at the course of acquisition of German plural marking by 11 German-learning children (Szagun, 2001). It was found that the plural suffix is used from about 1;8, or when the child has a mean length of utterance of 1.25 words. The speed of acquisition of each plural type differs, with *-n* being acquired most quickly, followed by *-e*, *- ø* and umlaut + *-e*. The remaining types (*-s*, umlaut + *-er* and umlaut alone) are acquired most slowly. Despite claims that *-s* is the default suffix (Clahsen, 1999; Marcus et al., 1995), which would predict that children overgeneralise this form greatly, this prediction is not supported by the data. Instead, children make errors in all types of plurals equally, including not marking plurals when needed, selecting the wrong suffix, over-marking by using two suffixes together, or under-marking by using only one of two necessary markers (e.g. umlauting but not suffixation, or suffixation without umlauting).

Table 4

Examples of errors in German children's plural productions (Szagun, 2001).

		Child's production	Target	
a)	Affixing *-n*	*Kind-er-n*	*Kind-er*	'children'
b)	Affixing *-s*	*Tiger-s*	*Tiger*	'tigers'
c)	Affixing *-e*	*Herz-e*	*Herz-en*	'hearts'
d)	Affixing *-er*	*Aut-er*	*Auto-s*	'cars'
e)	Partial marking	*Bäum*	*Bäum-e*	'trees'
f)	No marking	*Auto*	*Auto-s*	'cars'
g)	Other errors	*Bäuer*	*Bauer-n*	'farmers'

2. How are morphophonological alternations acquired?

Despite the great focus on the acquisition of morphology, there have been few studies into the acquisition of morphophonological alternations, such as the voicing alternation in Dutch and German. This type of morphophonological alternation is non-allophonic, because the members of the alternation are not in complementary distribution. Allophones are different phones that occur in different contexts, but correspond to the same phoneme (Peperkamp & Dupoux, 2002). To exemplify this, vowel nasalisation is allophonic in English, but phonemic in French. In English, vowels will be nasalised before nasal consonants but not elsewhere; compare the vowels of *man* [mæ̃n] and *mad* [mæd], both of which are categorised as the same vowel - /æ/ - by native speakers. In French the difference between [æ] and [æ̃] is phonemic, with minimal pairs such as *bas* [bæ] 'low' and *banc* [bæ̃] 'bench' (Peperkamp, Le Calvez, Nadal, & Dupoux, 2006; Seidl, Cristia, Bernard, & Onishi, 2009). Allophonic variation is easily acquired; by 11-months-old English-learning infants treat [æ] and [æ̃] as functionally equivalent (Seidl et al., 2009). It is assumed that because variants occur in complementary distribution the pattern can be derived on the basis of distributional cues, without semantic knowledge (Peperkamp & Dupoux, 2002). Distributional cues alone cannot be used to learn about non-allophonic variation, and as such, the voicing alternation of Dutch and German and similar alternation patterns are difficult to acquire. It has been claimed that the pattern will not be acquired fully until adolescence (Pierrehumbert, 2003).

It is proposed that learners begin with a period of pure phonotactic learning (Albright & Hayes, 2011; Hayes, 1999, 2009; Jarosz, 2011; Peperkamp & Dupoux, 2002; Tesar & Prince, 2004). At this point Dutch and German learners will become sensitive to the lack of voicing contrast in final position. However, they can only learn which paradigms contain a voicing alternation once they have the morphological, lexical and semantic knowledge to be able to compare members of the same paradigm. This also requires some cognitive processing abilities, rather than looking only at the surface forms.

Data from studies with Dutch- and German-learning children has supported the claim that the voicing alternation is difficult for children to acquire. The phonotactic constraint against voicing in final position is apparently easier; in a production task with children of 2;6 and 3;6 none of them erroneously used voicing in this position (Zamuner, Kerkhoff, & Fikkert, 2011). Dutch 16-month-olds do not discriminate voicing features word-finally, although they can discriminate place of articulation features in this position (Zamuner, 2006). Comparing these findings to those of Seidl et al. (2009) it seems that Dutch 16-month-olds have learned not to pay attention to voicing in this position because it does not typically occur and is not a useful cue for their further language acquisition. However, despite never producing voicing in word-final position, neither Dutch nor German toddlers have a robust knowledge that this is due to neutralisation. When asked to produce the singular of a nonsense plural form (a reverse wug-test), both Dutch and German children struggle with the task (Kerkhoff, 2007; Van de Vijver & Baer-Henney, 2011; Van Wijk, 2007; Zamuner et al., 2011). For example, children would be asked to produce the singular of *two sladden* or *two slatten.* In both cases the correct answer would be *one slat.* Performance in both type of trial was poor for both Dutch and German, with both groups having a tendency to repeat the plural form rather than produce the alternation (e.g. *two sladden - one sladden*). In non-alternating trials performance was slightly better. When asked to produce a plural from a singular (e.g. *one slat - two slatten/sladden*), children preferred not to produce an alternation (Kerkhoff & De Bree, 2005; Kerkhoff, 2007; Van de Vijver & Baer-Henney, 2011; Van Wijk, 2007). A similar pattern is attested in children's productions of real words, where overgeneralisations of [t] are common, for example saying *betten* for *bedden* ('beds', Dutch) or *Hunte* for *Hunde* ('dogs', German). Children's productions of complex words demonstrate a preference for the same value of a given property, in this case voicing, to occur in all members of the morphological paradigm (cf. "Paradigm Uniformity", Steriade, 2000 and references therein).

3. How are complex words represented in the mental lexicon?

How morphology, or morphologically complex words, is represented in the mental lexicon has been a topic of much discussion in the past decades. Because most literature relates to English it has also been referred to as "The Past-Tense Debate" (cf. Burzio, 2002; Pinker & Ullman, 2002; Pinker, 2006). Traditional approaches to grammar assumed that stems were represented in the mental lexicon, alongside morphological rules and suffixes, which, together would generate complex words. For example the stem form *walk* is stored, and there is a rule of past-tense formation stating that the suffix *-ed* must be added. Similarly, when processing speech, it was assumed that complex words would be decomposed for lexical access. Irregular inflections posed a problem for this system, as this rule will generate forms such as *go-ed* or *bring-ed*, instead of *went* or *brought.* Chomsky and Halle (1968) assumed that there were minor rules to account for irregular forms.

This view was first challenged in the 1980s by Rumelhart and McClelland (1986) who proposed a purely associationist model of past-tense formation. In their connectionist model, irregular forms are generated through pattern associations. Once the model has learned a number of forms it uses these associations to generate inflections of newly acquired words. This mechanism was argued to be applicable for both regular and irregular forms, removing the need for rules entirely. In addition, it was argued that complex forms are also represented in the mental lexicon, as whole units, and not only stems. This claim predicts that monomorphemic and morphologically complex forms behave in the same manner in the lexicon. Exemplar based models (Bybee, 1985) also assume that complex words are stored in their whole form, whether regular or irregular, and novel forms are inflected not by rules but by analogy to other forms in the lexicon. Both connectionist and usage-based models make use of patterns within subsets, for example, *sing-sang, ring-rang,* or *fling-flung, cling-clung, sling-slung.*

Hybrid, or dual-route models form the bridge between the two sides of the debate. Dual-route models (Baayen, Dijkstra, & Schreuder, 1997; Clahsen, 1999; Marcus et al., 1992; Pinker, 1998) propose that there is both a rule-based system and a representation system active. Strong versions of the dual-route model (Clahsen, 1999; Marcus et al., 1992; Pinker, 1998) assume a strict division between how regular and irregular words will be stored and accessed; regular forms are generated by rules and irregular forms are stored in their whole form. Less strict versions (e.g. Baayen et al., 1997; Stemberger & MacWhinney, 1986) propose that frequency has a role to play, and highly frequent lexical forms will also be stored in their whole-form which is computationally more economic.

With regard to acquisition, the question is whether children are aspiring to acquire a productive rule, a productive analogical system, or a combination of the two. A model of acquisition such as Dressler and Karpf's (1994) discussed above, assumes that the earliest stages of morphological acquisition proceed word-by-word, with whole-form storage of correct forms, but this is a passing phase until the productive pattern is established.

Dual-route theories claim that both lexical storage and rule application apply in parallel, and the active process will be the one that is completed first. An adult has encountered familiar irregular forms often in their lifetime, and these forms have a strong activation in the mental lexicon. When speakers try to produce, for example, the past tense of *go*, both pathways will be activated; one that tries to generate *go+ed* and the other that tries to retrieve *went* from the lexicon. Because of the high frequency of *went* the retrieval route will be faster. Children do not have the advantage of experience, and the regular route may initially be faster, thus giving rise to overgeneralisations.

Models of the mental lexicon have an impact on the interpretation of voicing alternations. In a rule-based model, stems are stored in the mental lexicon, but the stem form and the surface form do not always coincide, and a mechanism that mediates between the stem and surface form is required. It has traditionally been assumed that Dutch and German words that contain a voicing alternation in the morphological paradigm are represented with an underlyingly voiced obstruent. That is, a word like *bed* in Dutch is represented in the lexicon as /bɛd/, where /d/ becomes [t] in final position ([bɛt]) but not elsewhere ([bɛdən]). Whole-form storage models assume that the form represented in the mental lexicon is the same as the surface form, and no mediating mechanism is necessary; both /bɛt/ and /bɛdən/ are stored in the mental lexicon. When acquiring the system of voicing alternations according to both models the learner can only identify where an alternation is required once they are able to compare members of the morphological paradigm.

4. How do Dutch and German differ?

Dutch and German are both West Germanic languages, derived from the same historical language. They are also spoken in neighbouring countries, in close contact with one another. These factors give rise to many similarities between the two. Lexically there are many cognates or near-cognates where the common root is evident. Some examples are presented in Table 5, where final devoicing is also apparent. Despite these similarities there are also a number of differences between the two languages (besides the differences in plural marking described above), which may impact on, or interact with, the acquisition of voicing alternations.

Firstly, the role of voicing in the two languages differs. Voicing is a weak cue in Dutch, with a low functional load. Considering the voicing contrast is marked across the class of obstruents, for plosives Dutch has only /p,b,t,d,k/ and lacks /ɡ/ which is not a native phoneme of the language. With regard to voicing alternations there is a lexical gap and very few items contain a [p]~[b] alternation. Fricatives also fall in the class of obstruents, but fricative voicing is an unreliable cue in Dutch. In word-onset position in many areas of the Netherlands the voicing contrast is completely neutralized (Ernestus, 2000; van de Velde, Gerritsen, & van Hout, 1996), and in word-medial position fricative voicing is largely allophonic; long vowels precede voiced fricatives and short vowels precede voiceless fricatives. In German, in contrast, the voicing contrast extends, and is maintained, across the whole class of obstruents in all place of articulation. Further phonological differences are discussed in Chapters 2 and 3.

Table 5

(Near) Cognates of Dutch and German.

Dutch		*German*		*English*
beker	[bekər]	Becher	[bɛçɐ]	‘beaker’
brood	[broːt]	Brot	[broːt]	‘bread’
hond	[hɔnt]	Hund	[hʊnt]	‘dog’
paard	[paːrt]	Pferd	[pfeːɐt]	‘horse’
wolk	[vɔlk]	Wolke	[vɔlkə]	‘cloud’

In addition to the voicing contrast itself having greater functional load in German there are also lexical differences in the distribution of voicing alternations between the two languages. Corpus data from Child Directed Speech are presented in Chapter 3 showing that 63% of noun plurals in the German child’s input contain a voicing alternation, compared to only 32% in Dutch.

Taken together these cues may provide German-learning children with an advantage when acquiring voicing alternations. Firstly, German children simply hear more evidence for voicing alternations. They encounter alternations across the whole class of obstruents, whereas Dutch children’s evidence comes predominantly from the [t]~[d] alternation. Studies have shown that infants are able to form generalisations across abstract feature specifications (Maye, Weiss, & Aslin, 2008; Saffran & Thiessen, 2003; White, Peperkamp, Kirk, & Morgan, 2008), which would provide German infants with an advantage. Secondly, of the nouns heard, there is a greater chance in German that the stem-final obstruent should alternate in the plural than not. The opposite is true for Dutch. Thirdly, in infant-directed speech (IDS), parents emphasise elements of the language that are important. In one study, Japanese and French mothers were required to teach their infants novel names such as *Bicko* and *Beepa.* Japanese mothers were found to emphasise durational differences whereas French mothers emphasised spectral differences (Werker et al., 2007). If Dutch mothers do not value the voicing contrast as an important cue of the language then they will not emphasise this in their IDS, whereas German mothers may emphasise it more. It may not be a coincidence that German articulation sounds especially “accurate” to Dutch listeners (van Dommelen, 1983). In increasing the emphasis placed on the contrast they will also increase the acoustic saliency of the contrast, and more salient contrasts can be discriminated earlier (Narayan, Werker, & Beddor, 2010).

Acoustic marking of the voicing contrast differs between Dutch and German. In their seminal study Lisker and Abramson (1964) identified different duration of Voice Onset Time (VOT) as a primary marker of the voicing contrast cross-linguistically, where VOT is the "timing relation between voice onset and the release of occlusion" (Lisker & Abramson, 1964, p. 387). Typologically languages typically make use of three points on the VOT continuum of voicing lead, short-lag VOT and long-lag VOT. According to this definition, German is an aspirating language, marking the contrast between voiceless unaspirated stops with a short-lag VOT (voice onset occurs shortly after closure release) and voiceless aspirated stops with a long-lag VOT. Dutch, on the other hand is a prevoicing language, marking the contrast between voiced stops with negative VOT values (voicing lead, voice onset begins prior to closure release) and voiceless unaspirated stops with a short-lag VOT. Average VOT values are presented in Table 6, and Figure 2 visually exemplifies this. The point of note is that there is a conflict in acoustic form and phonemic categorisation; a voiceless, unaspirated stop is categorised as "voiceless" in Dutch but "voiced" in German.

Table 6

Average VOT durations in German and Dutch (Kager, Van der Feest, Fikkert, Kerkhoff, & Zamuner, 2007).

	Voicing Lead	*Short Lag VOT*	*Long Lag VOT*
German		16ms: b,d	51ms: p, t
Dutch	-80ms: b, d	0-25ms: p, t	

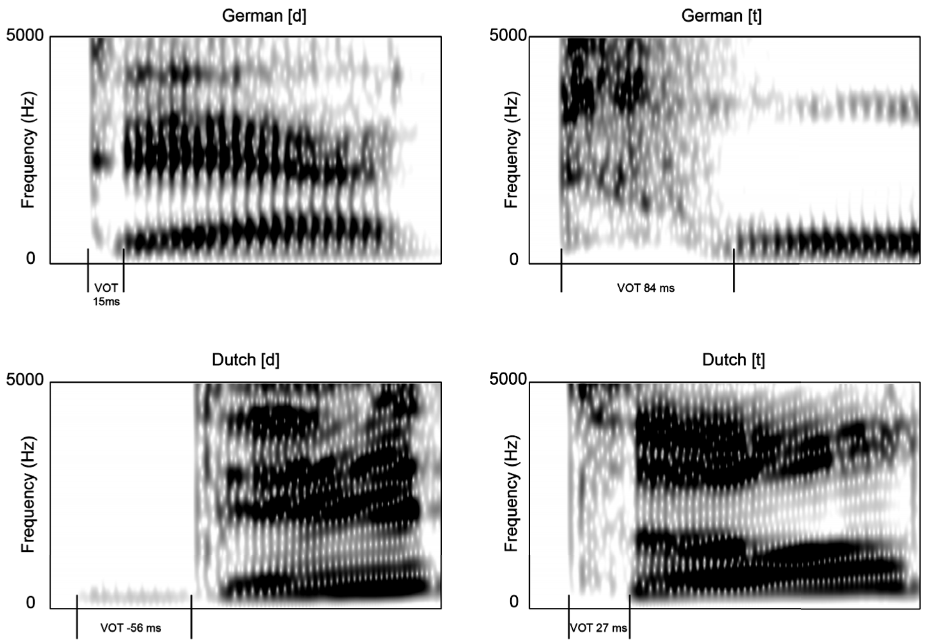

Figure 2. Spectrograms illustrating VOT in word-onset position in German and Dutch. Note the similarity between German [d] and Dutch [t]. These samples are taken from experimental stimuli of Chapter 2.

It is unclear whether this acoustical difference will have an impact on acquisition of the two languages, in particular the acquisition of voicing alternations. Neither contrast enjoys an early perceptual advantage. Studies of early perception of VOT differences have shown that infants are able to discriminate VOT contrasts within both the plus and minus regions of the continuum, regardless of how the voicing contrast is marked in their native language. This has been shown for infants learning Spanish, which is a pre-voicing language like Dutch (Lasky, Syrdal-Lasky, & Klein, 1975), English, an aspirating language like German (Aslin, Pisoni, Hennessy, & Perey, 1981) and Kikuyu, which only has one labial stop and therefore no contrast (Streeter, 1976). The voicing contrast is acquired earlier in production of children acquiring aspirating languages than prevoicing languages. Early studies on the acquisition of the voicing contrast in English have shown that the contrast is acquired by the age of 2 and a half years (Davis, 1995; Macken & Barton, 1980b). More recent data confirm that this holds for German too (Kager et al., 2007; Kehoe, Lleó, & Rakow, 2004). In Dutch the voicing contrast is not produced accurately by age 3

(Van der Feest, 2007), and reports of children acquiring other languages with pre-voicing such as Spanish, French, Thai or Hindi state that the contrast is often not acquired until around 5 years old (Allen, 1985; Davis, 1995; Gandour, Petty, Dardarananda, Dechongkit, & Mukngoen, 1986; Macken & Barton, 1980a). It is assumed that voicing lead is more difficult to articulate and therefore children cannot produce the contrast accurately, tending to "devoice" voiced stops (Macken & Barton, 1980a).

A further discussion surrounding the voicing contrast concerns how it should be represented at the phonological feature level. The classic view was to assume that the voicing contrast is phonologically the same for all languages, including Dutch and German, and speakers of both languages represent the feature [voice] (Lombardi, 1995; Mester & Itô, 1989; Wetzels & Mascaró, 2001). This interpretation, however, ignores the phonetic difference between the contrast cross-linguistically. For this reason many authors have proposed that the relevant feature for German is [spread glottis] and not [voice] (Iverson & Salmons, 1995; Jessen & Ringen, 2002; Jessen, 1998; Petrova, Plapp, Ringen, & Szentgyörgyi, 2006). In addition, it has often been discussed whether features are monovalent or bivalent; is the contrast between [+voice] and [-voice] (e.g. Wetzels & Mascaró, 2001) or [voice] and [Ø]. Iverson and Salmons (1995) posit multiple monovalent features, thereby proposing differences between voicing in Dutch and German at the feature level. They argue that voiceless stops are marked by [spread glottis] in German, and voiced stops are underspecified. In contrast, voiced stops are marked by [voice] in Dutch, and voiceless stops are underspecified. Kager et al. (2007) cite differences in production accuracy as support for this hypothesis, where both Dutch and German's productions are examples of neutralising to the unmarked.

The debate surrounding featural representations is relevant for representation of voicing alternations because it alters how alternations should be interpreted. If voicing alternations are understood as resulting from final devoicing, then in a language that specifies the voicing contrast with the feature [voice] has no problem; in final position this feature is neutralised to the unmarked value. However, if the voicing contrast is specified as [spread glottis], then in final position the contrast is neutralised through the addition of a feature, rather than loss (Iverson & Salmons, 2011).

5. Overview

This thesis addresses the question of how voicing alternations are acquired by Dutch and German children, a process at the interface of phonology and morphology. Chapters 2 and 3 explicitly contrast learners of Dutch and German, and Chapter 4 foucsses on Dutch-learners only. Children's productive and perceptual knowledge of voicing alternations are assessed in Chapter 4. Two age groups are contrasted to enable cross-linguistic comparison at different developmental stages.

2

Early sensitivity to morphophonological alternations in Dutch and German infants?

Introduction

Words are seldom uttered in isolation, and they are seldom monomorphemic. When combining words, inflectional affixes are often required to make an utterance grammatical. The core semantic meaning of the root remains unaltered and the inflectional morpheme(s) provide grammatical structure. That the meaning does not change can be seen in the word pair *cat* and *cats,* where both forms are members of the inflectional paradigm referring to the feline animal, but the number referred to differs. Creating complex words is not necessarily a simple matter of concatenating two morphemes as in this example; changes to the acoustic form may also occur. Consider the English plural marker *-s,* the form of which alternates depending on the final segment of the root. In order to create phonotactically legal sound sequences in English *-s* is realised as [s] following a voiceless obstruent (e.g. *cats*), [z] following a voiced segment (e.g. *dogs*) or [ɪz] following /s/ (e.g. *glasses*). The learner is therefore faced with two tasks, firstly, to discover that affixation does not change meaning, and secondly, to learn that any changes in form resulting from affixation also do not change the meaning, even if the resulting alternation involves contrastive phonemes of their language. The learner, in this scenario, must withhold the knowledge that /s/ and /z/ are contrastive phonemes that alter lexical meaning (cf. *sip* vs. *zip*). The question of how children acquire complex morphological structures is not new and can be traced back to Berko's seminal (Berko, 1958) paper in which the "wug-test" was first used to test children's ability to generalise morphological rules to novel forms. However, acquisition of the interplay between morphology and phonotactics has received less attention. In this paper we address how preverbal infants access the interaction of phonotactic restrictions and morphological complexity in Dutch and German.

Marquis and Shi (2012) recently provided evidence that preverbal infants already display some sensitivity to the grammatical nature of inflectional affixes. They found that 11-month-olds interpret bare roots and their inflected variants as related forms and not as different lexical items, thereby demonstrating that they have some understanding that inflectional affixes do not change the core meaning of a word. As young infants do not have a sizable vocabulary to make use of, it is assumed that they must be making use of the distributional statistics of inflectional suffixes, namely their high frequency and the great variability in roots that they affix to. This explanation is plausible, as we know that these two factors, frequency and variability, are important factors in language acquisition. The role of frequency in language learning is well established; in an early study using artificial language learning with adults, Valian and Coulson (1988) demonstrated that grammatical acquisition is facilitated by the high frequency of function elements. In infancy studies the importance of word or phonotactic frequency has been demonstrated, among others, in word-learning (Schwartz & Terrell, 1983; Storkel, 2001, 2003), word segmentation (Bortfeld, Morgan, Golinkoff, & Rathbun, 2005; Mattys & Jusczyk, 2001), speech production (Richtsmeier, Gerken, Goffman, & Hogan, 2009; Richtsmeier, Gerken, & Ohala, 2011) and phoneme categorization (Maye, Werker, & Gerken, 2002). Variability is also crucial, as the presence of variation allows infants to draw comparisons over events and establish that similarities must signify invariant structures (Gómez & Lakusta, 2004; Gómez, 2002; Richtsmeier et al., 2011; Singh, 2008).

Literature on morpho-syntactic acquisition provides further support for the hypothesis that infants may use the frequency of inflectional affixes and the variability of their co-occurrences to aid their morphological acquisition. Function words can be viewed as free morphemes with similar frequency and distributional patterns to inflectional morphemes. In one study Höhle, Kiefer, Schulz and Schmitz (2004) found that German-learning 16-month-olds are sensitive to the co-occurrence of determiners and nouns, and can use this knowledge to classify novel nouns. In addition, infants are also able to track non-adjacent dependencies, listening longer to grammatical sentences such as *is walking* than unnatural or ungrammatical constructions such as *can walking*. This has been attested in English (Santelmann & Jusczyk, 1998), Dutch (Van Heugten & Johnson, 2010) and German (Höhle, Schmitz, Santelmann, & Weissenborn, 2006). These infant studies speak against the suggestion that grammatical morphemes, because they are prosodically weaker than content words (cf. Cutler, 1993), are not perceived or encoded by infants. Lack of perception has been proposed as an explanation to account for the omission of functional elements in children's early telegraphic utterances (Brown, 1973), but infants must perceive grammatical morphemes in order to track them. Perception of function words was explicitly tested by Höhle and Weissenborn (2003), who found that German-learning 8-month-olds are able to detect function words in continuous speech, despite their prosodic weakness. English-learning infants are also sensitive to the presence of functors in the speech stream, and their presence facilitates segmentation of content words (Shi, Cutler, Werker, & Cruickshank, 2006). Shi et al. (2006) provided further evidence for infants' use of frequency; infants at both eight and eleven months make use of the highly frequent (and prosodically weak) functor *the* but not the less frequent, and equally weak, functor *she*.

Marquis and Shi's (2012) interpretation of their data is further corroborated by comparing their results to those of Jusczyk, Houston and Newsome (1999). In a head-turn study Jusczyk et al. (1999) found that 7.5-month-olds, when familiarised with *ham*, do not listen longer to *hamlet* than to a non-familiar word during the test phase. This indicates that infants, unlike the infants in Marquis and Shi's (2012) study, do not recognise *ham* and *hamlet* as being variant forms of the same word. Adopting Marquis and Shi's terminology, infants are not assigning *ham* and *hamlet* to the same core meaning. Instead they are (correctly) interpreting them as two separate lexical items. The form *-let* is arguably a derivational suffix, which, compared to an inflectional affix, is of low frequency and is limited in the variability of roots it co-occurs with.

In this study we explored the role that language-specific properties of frequency and variability play in early acquisition of morphophonological alternations. The alternation in question is the oft-discussed case of final devoicing, as attested in Dutch and German. In both languages there is a phonemic voicing contrast that is limited to word-initial and word-medial positions. Syllable-finally, and therefore word-finally, the contrast is neutralised. Voicing neutralisation gives rise to voicing alternations within an inflectional paradigm. A stem-final /d/ will be neutralised to [t] in final position, for example when not followed by an inflectional affix. If a vowel-initial suffix is added the obstruent is no longer in final position, and will be realised as a [d]. For example the Dutch word for 'bed', *bed*, is pronounced [bɛt] in the singular and *bedden* [bɛdən] in the plural due to the affixation of the suffix /-ən/. Infants must learn that /t/ and /d/ are phonemically contrastive in certain positions. One way of determining contrastiveness is to identify minimal pairs, for example, *tak* and *dak* are different Dutch lexical items with different semantic meanings, namely 'branch' and 'roof'. At the same time infants must learn that word-finally the contrast is neutralised, and that *bed* [bɛt] and *bedden* [bɛdən] are inflectional variants of the same lexical item. In order to succeed at this, infants must have knowledge of the phonotactics of their language and of morphophonological alternations.

There is a body of research suggesting that infants develop knowledge of their language-specific phonotactics during the latter part of their first year. English-learning 9-month-olds listen longer to words with phonotactically legal clusters than with illegal clusters (Friederici & Wessels, 1993), and longer to highly frequent patterns than less frequent patterns (Jusczyk, Luce, & Charles-Luce, 1994). 9-month-olds can also use the phonotactics of their language to help them identify word-boundaries (Mattys, Jusczyk, Luce, & Morgan, 1999; Mattys & Jusczyk, 2001). In all of these cases, infants display sensitivity to the frequency of specific sound combinations and sequences.

Neutralisation is a different type of phonotactic restriction than a sequencing restriction, and one that has received less attention in the infancy literature. In order to acquire the voicing alternation, infants must be attentive to the ends of words. In one study Saffran, Newport and Aslin (1996) have provided evidence that in an artificial language paradigm, adults learn ends of words before beginnings; participants confused words and part-words resembling the ends of words more often than words and part-words that resembled beginnings of words.

Tincoff and Jusczyk (1996) also found that English-learning infants at seven and a half months old are sensitive to word endings, noticing the difference between *bike* and *bipe.* Furthermore, infant studies that have controlled for position in the word have show that infants can attend to segments in word-initial as well as word-final position (Friederici & Wessels, 1993; Mattys et al., 1999; Mattys & Jusczyk, 2001). However, word-initial position seems to be more salient to infants and some studies have found that infants pay attention to word onsets but not to endings (Altvater-Mackensen & Fikkert, 2010; Jusczyk, Goodman, & Baumann, 1999; Zamuner, 2006). Notably, Zamuner (2006) found that Dutch-learning 9- and 11- month-olds are not sensitive to changes in word-final voicing or place of articulation. Dutch and German infants can only acquire the voicing alternation if they are attentive to the (lack of) voicing word finally.

Theories of learnability of morphophonological alternations propose that infants must acquire phonotactics and be morphologically aware before they can acquire morphophonological alternations (Hayes, 1999; Peperkamp & Dupoux, 2002; Tesar & Prince, 2003). Morphological awareness is taken to be the knowledge that words may be polymorphemic and that inflectional morphemes do not alter the core meaning of a word. These theories focus on the lexical acquisition of morphophonological alternations, deeming acquisition to be the point at which the child knows which lexical items with a stem-final [t] require an alternation in their inflected form and which do not. Infants are predicted to initially represent morphologically complex forms without parsing them for morphological complexity. Once they have posited a semantic link between members of the same inflectional paradigm they can cross-reference the phonological forms and come to the conclusion that there is an alternation present in the paradigm. This paper focusses on one of the earliest phases in the acquisition of morphophonological alternations. We investigated preverbal infants' sensitivity to voicing alternations using the distributional statistics that they have access to, specifically frequency and variability. As evidenced by Marquis and Shi (2012) and other literature on phonotactic learning, by the end of the first year infants have at least some morphological awareness and knowledge of language-specific phonotactics, both of which are predicted to be precursors to acquiring morphological alternations. We investigated whether infants can combine these sources of information into an early form of morphophonological awareness, asking whether preverbal infants were sensitive to the possibility that a morpheme may have more than one surface form, and that a voicing contrast does not always signify a lexical contrast. We contrasted Dutch- and German-learning infants because sensitivity to phonotactics and inflectional morphology in preverbal infants stems from the distributional statistics of an infant's native language. These two languages both neutralise the voicing contrast syllable- and word-finally, but the role of voicing, the distribution of alternations and plural formation differs between the languages.

Despite both Dutch and German having a voicing contrast that is neutralised syllable- and word-finally, there are a number of crucial differences in the voicing contrast between the languages that we expect infants to be sensitive to. Firstly, the functional load of the voicing contrast in the two languages differs. Voicing is a weak cue in Dutch, particularly in fricatives where there are very few minimal word-pairs that differ only in the [voice]-specification of the fricative, there is no voicing contrast in velar fricatives, and in many regions of the Netherlands speakers realise all word-initial fricatives as voiceless (Ernestus, 2000; van de Velde, Gerritsen, & van Hout, 1996). There is minimal evidence for the voicing contrast in velar plosives as /ɡ/ is not a native phoneme of the language, appearing in a few loan words such as *goal* and *buggy*. With regard to alternations, there are also very few items where /b/ alternates with [p]. In German the voicing contrast is more relevant, and is maintained across the whole natural class of obstruents. Neutralisation therefore occurs across the whole class (/p/-/b/, /t/-/d/, /k/-/ɡ/, /f/-/v/, /s/-/z/), and German infants are provided with more variable information than Dutch infants because they encounter the voicing contrast across different places and manners of articulation. Dutch infants are limited to basing their knowledge of voicing alternations on the underlying representations of the alveolar plosives /t/ and /d/, both surfacing as [t] in final position.

Secondly, there are differences in assimilation patterns in the two languages. Both languages display voicing assimilation across word and morpheme boundaries. Dutch has both progressive and regressive voicing (Booij, 1995). Voiceless obstruents before a voiced stop typically undergo regressive voicing assimilation and will surface as voiced, for example the medial /kd/ of *zakdoek* ‘handkerchief’ becomes [gd] (although this is not as stable as has previously been assumed, cf. Ernestus, Lahey, Verhees, & Baayen, 2006). Progressive voicing assimilation, or progressive devoicing, applies to underlyingly voiced fricatives following a voiceless plosive, for example the /pv/ in *opvallend* ‘remarkable’ becomes [pf][1]. In order to apply assimilations correctly, speakers must be sensitive to the manner of articulation of the second obstruent. German has only one predominant assimilation pattern; progressive devoicing assimilation. Voiced plosives are devoiced following a voiceless obstruent, e.g. *wegbringen* /kb/ becomes [kp] (Kohler, 1977).

Thirdly, Dutch voiced coronal plosives are subject to an optional alternation between /d/ and [j] or [w]. For example, *rode* ‘red’ may be pronounced [rodə] or [rojə], and *oude* ‘old’ may be [ɔudə] or [ɔuwə] (Booij, 1995). Such an alternation is not present in German.

Taken together, these differences across the phonological systems predict differences in how, and at what pace, Dutch and German infants may acquire the voicing contrast and associated voicing alternation. On the one hand, German infants are presented with more variable information across words about the voicing contrast across different places and manners of articulation, and the realisation of voicing is subject to less variation from assimilation or conflicting alternations. This may aid their acquisition of the voicing contrast and voicing alternations as it allows them to form generalisations and more stable representations. Dutch infants are faced with less variation within words in terms of place and manner of articulation in the voicing alternation, but much variation due to assimilation, conflicting alternations and greater unsystematic within-speaker variation than their German counterparts. This may lead Dutch infants to view the voicing contrast as optional, and less important for word identification.

At a lexical level there are also differences in the frequency of occurrence of voicing alternations. In a corpus study of child directed speech in Dutch and German (Chapter 3 of this thesis), we found that of all the singular-plural pairs with a stem-final obstruent, i.e. a potentially alternating context, only 32% of Dutch tokens contain a voicing alternation whereas 63% of the German tokens do. Although there is strong evidence that type frequency is important in establishing

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[1] It should be noted, however, that progressive voicing assimilation is also attested in stop clusters approximately 25% of the time (Ernestus et al., 2006).

paradigmatic links (e.g. Ernestus & Baayen, 2003, 2004) token frequency also has a role to play in acquisition. For example, hearing phonetically variable tokens from different speakers may aid the formation of abstract representations (Pierrehumbert, 2003; Richtsmeier, Gerken, & Ohala, 2008; Richtsmeier et al., 2011).

An additional consideration is how parents judge the importance of the voicing contrast in their language and how they mark it in their speech to the infant. Cross-linguistically caregivers have been shown to emphasise the contrasts important to the language being acquired (Werker et al., 2007). If German parents view voicing as an important contrast for their infant to acquire they may add emphasis to this in their speech, thereby supporting their child's acquisition of this contrast. Dutch parents, on the other hand, may be sensitive to the weakness of voicing as a cue in their language and perceive other features as more important, thereby paying less attention to the voicing contrast.

This study investigates whether Dutch- and German-learning infants are sensitive to properties of inflectional morphology in their native language. We further investigated whether they are able to incorporate this morphological knowledge with phonotactic knowledge, and assign bare roots and inflected form to the same lexical item when there is a voicing alternation as well as suffixation. We used the headturn preference procedure (HTPP) (Jusczyk & Aslin, 1995) and data from two experiments in each language are reported here. We first attempted to replicate the effect found by Marquis and Shi (2012) using the HTPP rather than a visual fixation procedure. In these experiments infants were familiarised on passages containing two monosyllabic, monomorphemic words with a final /t/ (e.g., *wet*). They were subsequently tested on the bisyllabic plural form of these two words (e.g., *wetten*), as well as two new words. A difference in orientation time to familiarised and novel words during the test phase would indicate that they are assigning monomorphemic and inflected forms to the same lexical entry. The second experiment in each language was identical to the first, except that the final segment of the monomorphemic form was /d/ which, due to word-final neutralisation, surfaces as [t]. In the test phase the inflected bisyllabic word had a medial voiced segment, [d], (e.g. *wet-wedden*). Again, a difference in infants' orientation time to familiarised and novel items would indicate that they are differentiating between the two, suggesting that they are able to assign pairs of inflected words to the same morphological paradigm despite the occurrence of a voicing alternation. No difference in orientation times would indicate that they are treating [t] and [d] as contrastive phonemes. That is, *wet* and *wedden* are being perceived as two separate lexical items.

9-month-olds were chosen for this study because we know that they already display sensitivity to language-specific phonotactics (e.g. Friederici & Wessels, 1993; Jusczyk et al., 1994; Mattys et al., 1999; Mattys & Jusczyk, 2001). This age-group is also the youngest age at which Dutch infants have previously shown segmentation abilities in a behavioural paradigm (Houston, Jusczyk, Kuijpers, Coolen, & Cutler, 2000; Kuijpers, Coolen, Houston, & Cutler, 1998). In addition, if infants of nine months old succeed in the first condition with no alternations, we will have shown that sensitivity to inflectional affixation develops earlier than eleven months of age (cf. Marquis & Shi, 2012).

Experiment 1A & B: Dutch

Method

Participants.

Twenty-four monolingual Dutch-learning 9-month-olds with no family history of language problems participated in each experiment (Experiment 1a: mean age = 276 days; range: 260-293 days; 16 girls, 8 boys; Experiment 1b: mean age = 281 days; range: 268-291 days; 12 girls, 12 boys). An additional 17 infants were tested for each experiment but excluded from analysis. This high drop out rate resulted from an administrative error whereby a number of infants participated that did not conform to the pre-defined inclusion criteria. In Experiment 1a ten infants were excluded due to fussiness, two were not being brought up in a monolingual environment and five infants had at least one parent with reported dyslexia. In Experiment 1b eleven infants were excluded due to fussiness and six had a parent with dyslexia. Our definition of fussiness is described in the section Data Analysis below. Infants were tested at the Baby Research Center of the Radboud University Nijmegen, The Netherlands.

Stimuli.

Experiment 1a.

During the familiarisation phase infants heard two of four monosyllabic words with a final /t/ embedded in passages. The target words were monosyllabic forms with a stem-final /t/, namely, *dot* [dɔt], *mat* [mɑt], *pit* [pɪt] and *wet* [ʋɛt]. All four words are existing Dutch nouns, therefore we can be certain that they conform to the phonotactic structure of the language. The intention was to use target words that would not be familiar to young infants. All words selected were of low frequency and none of them are listed in the Lexilijst-Nederlands (Schlichting & Lutje Spelberg, 2002), a normalised vocabulary list for children up to 27 months old. As such, we could be reasonably certain that none of these items are familiar to 9-month-olds and, for the purposes of this experiment could be treated as nonce words.

Each passage consisted of eight sentences, and each sentence contained exactly one token of the target word. Sentences within each passage were always presented in the same order (see Appendix for passages). The target word was located at different positions within the sentence to maximise the variability of its acoustic realisation with regards to prosody, intonation and co-articulation. Acoustic measures of the target word are presented in Tables 1a and 1b.

During the test phase infants heard a list of isolated plural forms of the target words, all of which were inflected with *–en: dotten* [dɔtən], *matten* [mɑtən], *pitten* [pɪtən] and *wetten* [ʋɛtən]. All of these plural forms appear in the CELEX database (Baayen, Piepenbrock, & Van Rijn, 1993) with a frequency greater than 0. Fifteen different tokens of each word were concatenated into a list with a duration of 23 s. The duration of the pause between tokens varied to reduce predictability for the infant and to ensure the length of the lists were comparable, despite differences in the duration of each word. Acoustic analyses of these tokens are also presented in Table 1a, and broken down by syllable in Table 1b. The first syllable always received primary stress in these words and the second syllable is a weak schwa syllable[2].

A female native speaker recorded all stimuli in an infant directed manner. It should be noted that although Dutch speakers often delete the final [n] following schwa, in the careful speech of the plural tokens elicited for this experiment the final nasal was present. Other native speakers listened to the prepared stimuli and agreed that they sounded natural.

Experiment 1b.

Infants were familiarised on passages containing two of four monosyllabic words with a stem-final /d/ that is neutralised to [t] in this context: *mud* [mʏt], *pad* [pɑt], *tod* [tɔt], *wed* [ʋɛt]. Words were selected according to the same criteria and to be minimally different to the items used in Experiment 1a. Items were embedded in the same eight-sentence passages as Experiment 1a. Each passage had a duration of 25 s.

During the test phase infants heard lists of all four of the test items in its plural form: *mudden* [mʏdən], *padden* [pɑdən], *todden* [tɔdən], *wedden* [ʋɛdən]. With the exception of *mudden* all of these bisyllabic forms are attested in the CELEX corpus (Baayen et al., 1993) with a frequency greater than 0. Each list contained 15 different tokens of one item and was 23 s long. Acoustic characteristics of all stimuli are presented in Tables 2a and 2b.

All stimuli were recorded by the same native speaker as Experiment 1a, who was instructed to speak in an infant directed manner. Further native speakers listened to the stimuli and agreed that they sounded natural.

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[2] Stress is realised by increased duration, pitch and/or intensity. Although the first syllable in our stimuli was not always longer than the second, this can be attributed to final lengthening when words are spoken in isolation (e.g. Klatt, 1976) rather than stress.

Table 1a

Acoustic characteristics of the stimuli in Experiment 1a (mean values and SDs in parentheses).

		Duration (ms)	*Pitch (Hz)*	*Max Intensity (dB)*
Items in passages	*dot*	382 (80)	273 (46)	81 (2)
	mat	470 (89)	292 (15)	78 (3)
	pit	357 (73)	243 (38)	75 (3)
	wet	376 (94)	255 (45)	78 (2)
Items in lists	*dotten*	647 (60)	296 (9)	80 (1)
	matten	683 (33)	303 (9)	79 (1)
	pitten	499 (33)	286 (14)	77 (2)
	wetten	658 (55)	303 (9)	79 (1)

Table 1b

Acoustic characteristics of syllables of stimuli in the test phase of Experiment 1a (mean values and SDs in parentheses).

	Duration (ms)		*Pitch (Hz)*		*Max Intensity (dB)*	
	1st syllable	*2nd syllable*	*1st syllable*	*2nd syllable*	*1st syllable*	*2nd syllable*
dotten	281 (44)	366 (26)	288 (10)	288 (18)	80 (1)	76 (3)
matten	306 (29)	377 (21)	246 (42)	303 (9)	79 (1)	72 (2)
pitten	168 (8)	332 (36)	253 (24)	285 (33)	76 (2)	75 (3)
wetten	286 (33)	371 (39)	227 (33)	302 (11)	79 (1)	72 (2)

Table 2a

Acoustic characteristics of the stimuli in Experiment 1b (mean values and SDs in parentheses).

		Duration (ms)	*Pitch (Hz)*	*Max Intensity (dB)*
Items in passages	*mud*	481 (71)	291 (10)	75 (2)
	pad	375 (91)	246 (38)	83 (3)
	tod	399 (93)	233 (39)	80 (2)
	wed	447 (76)	249 (44)	79 (3)
Items in lists	*mudden*	687 (37)	298 (11)	79 (1)
	padden	548 (25)	300 (11)	83 (2)
	todden	557 (16)	294 (17)	82 (2)
	wedden	666 (32)	304 (10)	79 (1)

Table 2b

Acoustic characteristics of syllables of stimuli in the test phase of Experiment 1b (mean values and SDs in parentheses).

	Duration (ms)		*Pitch (Hz)*		*Max Intensity (dB)*	
	1st syllable	*2nd syllable*	*1st syllable*	*2nd syllable*	*1st syllable*	*2nd syllable*
mudden	263 (23)	424 (30)	287 (9)	292 (16)	79 (1)	79 (1)
padden	177 (17)	371 (28)	259 (34)	298 (34)	83 (2)	80 (3)
todden	200 (13)	357 (20)	281 (26)	291 (18)	82 (2)	79 (1)
wedden	288 (22)	377 (34)	274 (41)	300 (12)	79 (1)	77 (1)

Procedure and apparatus.

The procedure used was a version of the Headturn Preference Procedure (HTPP), identical to Experiments 2 and 3 of Jusczyk, Houston, et al. (1999). Infants were familiarised to two (of the four) monosyllabic words embedded in passages and during the test phase they were presented with lists of isolated tokens of all four words in their bisyllabic, plural form.

Infants sat on their caregiver's lap in the centre of a three-sided-booth with a blue light mounted in the centre of the panel in front of the infant and red lights mounted in the side panels. Concealed loudspeakers were located underneath the side lamps. The experimenter observed the infant via a camera located beneath the centre lamp and used a computer keyboard to code the infant's headturns. The experiment was presented, controlled and orientation times recorded using *Look* (Meints & Woodford, 2008). The caregiver and experimenter both wore closed headphones and listened to masking music interspersed with speech for the duration of the experiment. The caregiver was further instructed not to interact with their child.

A trial began by flashing the centre light to get the infant's attention. Once the child had oriented to the centre, the lamp was extinguished and one of the side lamps began to flash. When the infant turned their head at least 30° in the direction of the flashing lamp the auditory stimulus began to play from the loudspeaker on that side. If the infant looked away from the lamp for two consecutive seconds the trial ended and the centre light began to flash once more. If the infant looked briefly away from the side lamp and returned within 2 s the trial did not end.

The experiment began with a familiarisation phase, during which infants heard alternating trials of the two target passages. In Experiment 1a half of the infants were familiarised on passages containing *dot* and *mat*, and half to passages containing *pit* and *wet*. Half of the infants participating in Experiment 1b were familiarised to *tod* and *mud* and half to *pad* and *wed*. The familiarisation phase continued until infants had been exposed to each passage for 45 s, which corresponded to hearing the target word approximately 16 times. If an infant reached the familiarisation criteria for one passage before the other they were presented with only the non-familiarised passage until 45 s of listening was reached. Four pseudo-random orders were created varying the side of presentation of each trial and which of the two items the infant was presented with first.

The test phase began immediately after the familiarisation criteria had been reached for both items. During the test phase infants were presented with three blocks of four lists of isolated bisyllabic plural words, for a total of 12 test trials. For each infant two of the words were the plural form of the words they had heard during the familiarisation phase and two were novel plural forms. Each list occurred once per block and the order and side of trial presentation was pseudo-randomised within each block.

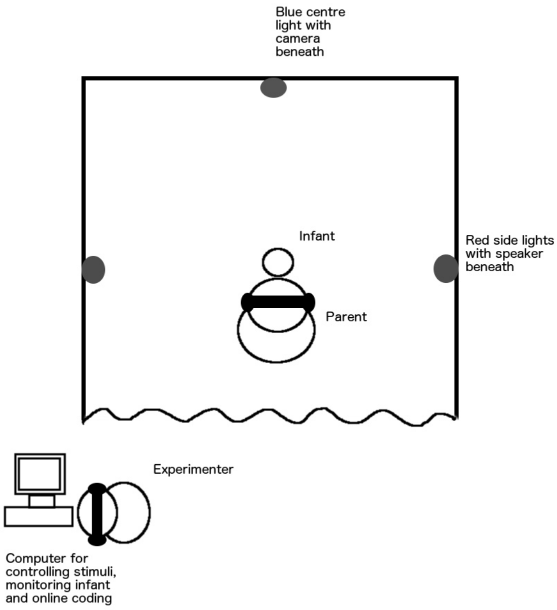

Figure 1. Experimental setup of HTPP

Data preparation and analysis.

A number of exclusion criteria were applied to ensure that only trials during which the infant was participating in the task were included in the analysis. Infants were excluded if they did not complete the test phase due to fussiness, such as crying to an extent that the experiment had to be stopped (Experiment 1a = 9 infants, Experiment 1b = 11 infants). To minimise floor and ceiling effects, individual trials of the remaining infants' data were excluded if the infant did not orientate to the target lamp for at least 1 s (Experiment 1a = 7 trials, Experiment 1b = 15 trials), or if their longest look was longer than 22 s (Experiment 1a = 11 trials, Experiment 1b = 8 trials). We required infants to have an average longest looking time across all trials of at least 3 s, and all participants in Experiments 1a and 1b met this criterion. Finally, we ensured that missing trials were distributed across all infants, making sure that each infant participated in (i.e. contributed to the final data-set) at least seven of the possible twelve trials. As there were an equal number of novel and familiar trials (six each), we were certain that each infant participated in both novel and familiar trials. Remaining for analysis was data from 24 infants per experimental condition, each of whom had successfully participated in at least 7 of the 12 test trials with a continuous orientation time of at least 1 s per trial.

Both total orientation duration and longest orientation time (uninterrupted look) were measured and analysed. Mean total orientation time is the more common analysis for headturn studies, however, there is reason to believe that the longest look may be a more sensitive measure of infants' cognitive processing. In the visual processing literature the longest look is the standard dependent measure used. It is assumed that infants will look at an object for long enough to build a mental representation of it, and look away once their mental representation is complete (de Barbaro, Chiba, & Deák, 2011). These studies are comparable to a headturn study in that they investigate infants' cognitive processing in one modality. Once infants have built a representation of the stimuli, either visual or auditory, they look away as a sign that they have processed the stimuli. Infants may return their gaze to the side lamp simply because there is nothing else of interest to focus their attention on. A similar point is made by Echols, Crowhurst, and Childers (1997) who only analysed infants' looking behaviour during the first 10 seconds of a trial. They argue that relevant variability occurs within this window, and variability introduced later in the trial can be attributed to extraneous factors.

The key difference between the longest look measure and total orientation time measure concerns how a look away should be interpreted. Typically, in the headturn procedure, it is assumed that if the infant looks away from the side lamp and redirects their attention back to the lamp in less than two seconds this does not constitute a loss of attention. To the best of our knowledge, the reason for assigning two seconds as the meaningful duration for a look away has not been justified in the literature. Assuming looking behaviour is a reflection of cognitive processing, as is the crucial assumption of the HTPP, it is likely that there is a large difference in underlying processing of an infant who frequently switches attention to and from the side lamp, and an infant who focusses on the light for a period of time before finally looking away. Taking only total orientation time as a measure conceals this information.

The argument for taking the infants' longest look could also apply as an argument for measuring only the duration of the infants' first look to the target lamp. In our data these measures largely coincided. In 76% of all trials in Experiments 1a and 1b the infants' first look was also their longest look. Of the trials where the first look was not the longest look, the first look was shorter than 2 s in 42% of the trials. This suggests that in these cases the first look was not a fixation by the infant but more likely resulted from the experimenter misinterpreting the infants' behaviour, for example by starting the trial before the infant had fixated on the centre lamp. Furthermore, the mean longest look in both experiments was shorter than 10 seconds, suggesting that our measure was comparable to that of Echols et al. (1997).

Longest look has previously been used in infant language studies albeit in different experimental paradigms. Schafer and Plunkett (1998) use this measure in an intermodal preferential looking task, arguing that the deterioration in infants' attention as the trial progresses dilutes the total looking measure. This argument can also be applied to a headturn procedure, even though it is infant controlled.

Infants' looking behaviour during the test phase was coded offline by an experienced coder using *SuperCoder* (Hollich, 2003). The coder was not aware of which stimulus the infant was presented with in a given trial or which items the infant had heard during the familiarisation phase. A second trained coder also coded data from 25% of participants to assess the reliability of coding. Inter-coder reliability for both measures of total orientation time and longest looks was high with Pearson product-moment correlations of the total orientation time of 0.93 ($p < .001$) for Experiment 1a and 0.99 ($p < .001$) for Experiment 1b. Similar reliability was established for the longest look measure, with Pearson product-moment correlations of Experiment 1a of 0.89 ($p < .001$) and Experiment 1b of 0.99 ($p < .001$).

Results and discussion

Data from Experiments 1a and 1b were analysed together. Mean looking times to each word across the three blocks were calculated and an analysis of variance was conducted examining the effects of the within-subject factor Familiarity (familiar versus novel), the between-subject factor Morphophonology (non-alternating versus alternating) and the interaction of these two factors. In addition, we also calculated mean longest looking time to each word across the three blocks and conducted the same analysis on this data. In the analyses of both measures we defined a p-value of less than .05 as significant, and between .05 and .099 as marginally significant.

Turning first to the analysis of total orientation times, our analysis revealed no main effect of Familiarity, $F(1,46) = 1.09$, $p = .3$, but a significant main effect of Morphophonology, $F(1,46) = 6.86$, $p = .01$. Infants showed no preference for either familiar or novel trials, but overall orientation times were longer in the non-alternating condition (mean = 8.9 s, SD = 2.7) compared to the alternating condition (mean = 7.25 s, SD = 2.7). There was no interaction of Familiarity by Morphophonology, $F(1,46) = .926$, $p = .34$ indicating that the difference in orientation time to familiar and novel trials did not differ between conditions. In the non-alternating condition mean orientation time to familiar items was 8.4 s (SD = 2.8) and to novel items 9.4 s (SD = 2.6), with 9 of the 24 infants preferring to listen to familiar rather than novel words. Mean orientation times in the alternating condition were 7.2 s (SD = 2.7) to familiar trials and 7.3 s (SD = 2.7) to novel trials, and 11 of the 24 infants displayed a familiarity preference. Pairwise comparisons of the effect of Familiarity within each group further revealed that the difference in orientation time to novel and familiar trials did not reach significance in either group (non-alternating condition: $F[1,22] = 2.01$, $p = .16$, alternating condition, $F[1,22] = .003$, $p = .95$).

A similar pattern of results is seen if the average duration of the longest look is taken as the dependent measure. We found no main effect of Familiarity,

$F(1,46) = .25$, $p = .62$, and no interaction of Familiarity and Morphophonology, $F(1,46) = 1.2$, $p = .28$. Again, orientation times to novel or familiar trials did not differ in either condition. The effect of Morphophonology also approached significance in this analysis, $F(1,46) = 3.99$, $p = .05$: infants had longer listening times in the non-alternating condition than the alternating condition. Mean longest orientation time to familiar words in the non-alternating condition was 6.6 s (*SD* = 2.3) and to novel trials 7.2 s (*SD* = 2.03). Nine of the 24 infants displayed a familiarity preference. In the alternating condition the duration of the mean longest look to familiar trials was 6.03 s (*SD* = 2.4) and to novel trials 5.8 s (*SD* = 1.9), with 12 of 24 infants showing a familiarity preference.

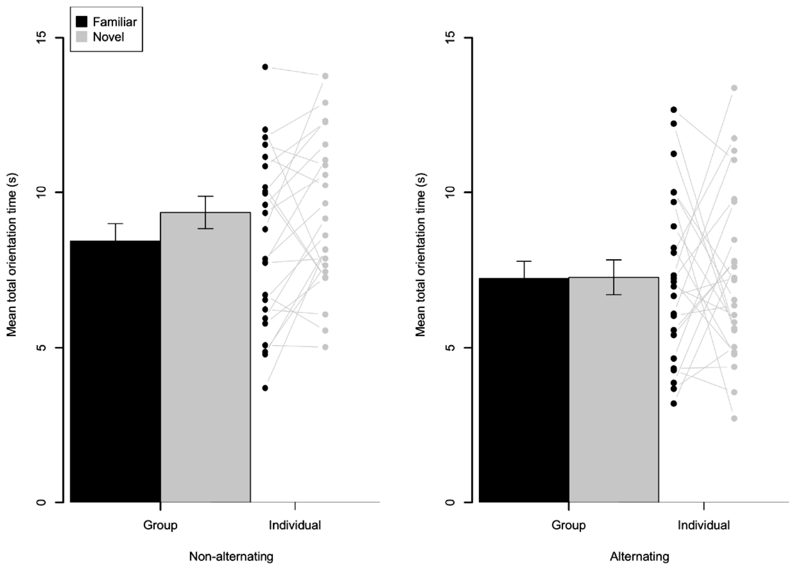

Figure 2a. Mean total orientation times (and SE of mean) to familiar and novel items during the test phase of Experiment 1a (non-alternating condition) and 1b (alternating condition).

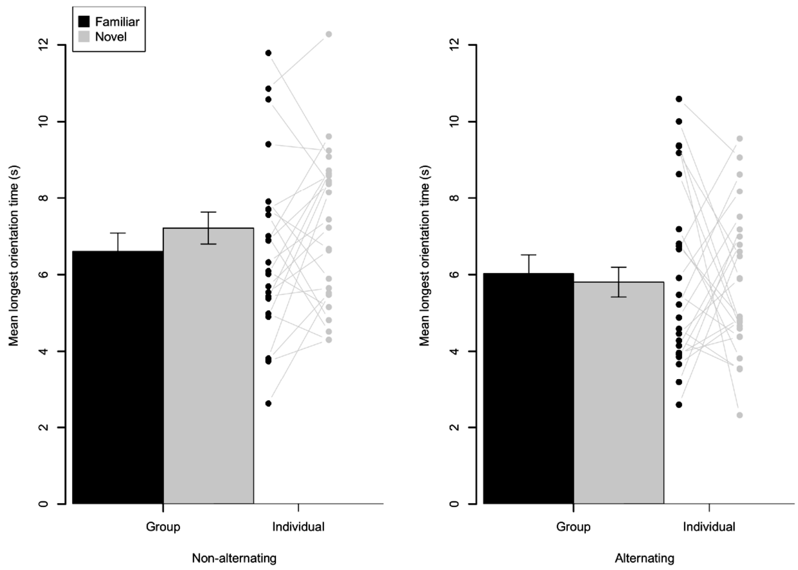

Figure 2b. Mean longest orientation times (and SE of mean) to familiar and novel items during the test phase of Experiment 1a (non-alternating condition) and 1b (alternating condition).

The question of interest in these experiments was whether infants in either group displayed a preference for familiar or novel stimuli during the test phase, thereby indicating an ability to differentiate between the two types of stimuli. Regardless of the measure analysed, either mean total looking time or mean longest looking time, our results show that infants did not display a consistent preference for novel or familiar stimuli. We predicted that infants in Experiment 1a, with only suffixation, would succeed in this task. Following Marquis and Shi (2012) we hypothesised that infants would be sensitive to the high frequency and variability of inflectional affixes and be able to associate bare stems and inflected forms to the same lexical entry. This was not confirmed. Instead, our results speak in favour of an explanation that assumes that Dutch 9-month-olds do not recognise *dot* and *dotten* as being variants of the same form. Our result bears greater similarity to that of Jusczyk, Houston, et al. (1999), who concluded that infants treat embedded forms (e.g. *ham-hamlet*) as separate words. Considering the result of Experiment 1a, it is unsurprising that in Experiment 1b, with the addition of a voicing alternation between the stem and inflected form, infants failed to recognise familiarised items.

Dutch-learning 9-month-olds do not yet show sensitivity to inflectional morphology and the intraparadigmatic links between stems and inflected form, whether marked by inflection alone or by suffixation and a voicing alternation. They are not yet sensitive to the frequency and variability properties of inflectional affixes and treat *dot* and *dotten* as separate lexical items. However, as noted by Aslin and Fiser (2005) and Kooijman, Johnson and Cutler (2008), this conclusion needs to be treated with caution, as a lack of preference cannot be interpreted as a failure to discriminate. If infants display a preference for one stimulus over the other it can be inferred that they are discriminating between the stimuli. The reverse is not necessarily true; lack of preference need not imply lack of discrimination. Furthermore, on the basis of two experiments in which infants displayed no preference, we cannot exclude the impact of extraneous factors. However, previous research has shown that Dutch 9-month-olds do show segmentation abilities using the HTPP (Houston et al., 2000; Kuijpers et al., 1998).

The result of Experiment 1a was not in line with our predictions. From previous literature we know that Dutch 9-month-olds can segment words from fluent speech using this experimental paradigm, and that English- and German-learning 8-month-olds can use prosodic differences to differentiate functors from content words (Höhle & Weissenborn, 2003; Shi et al., 2006). However, prior research has also shown that Dutch infants tend to lag approximately a month behind their American-English-learning peers in their early language abilities, including segmenting words from fluent speech. For example, American infants succeed in segmenting words from fluent speech at 7.5 months, whereas Dutch infants display this ability only at 9 months of age (Kuijpers et al., 1998).

We were interested in comparing language-specific properties of infants' input language on their ability to identify stem forms in different morphological contexts, including affixation and voicing alternations. Therefore we replicated Experiment 1 with German-learning infants. Our original hypothesis was that German infants would behave differently to Dutch infants because of the higher functional load of the voicing contrast in German. In light of the results of Experiment 1, it appears that the voicing contrast is not the only relevant contrast to be examining, and the cross-linguistic contrast remains interesting. Whereas one could argue that Dutch infants do not yet link morphologically related forms to the same lexical entry because of the more general delay in their acquisition process (cf. later development of segmentation abilities), this delay has not been shown to exist so strongly for German-learning infants. We predicted, therefore, that German infants would be in advance of their Dutch-learning peers in the acquisition of inflectional morphology and morphophonological alternations.

Experiment 2A & 2B: German

Method

Participants.

Twenty-four monolingual German-learning 9-month-olds with no familial risk of dyslexia participated in each experiment (Experiment 2a: mean: 276 days; range: 260-289 days; 12 girls, 12 boys; Experiment 2b: mean: 276 days; range: 258-287 days; 10 girls, 14 boys). An additional nine infants participated in Experiment 2a but were excluded due to technical error ($n = 4$) or fussiness / not participating in enough trials ($n = 5$). Twelve infants were excluded from the analysis of Experiment 2b for the same reasons (technical error $n = 2$; fussiness / not participating in enough trials $n = 10$). Fussiness was defined in the same way as Experiment 1. Infants were tested at the BabyLab of the University of Potsdam, Germany.

Stimuli.

Experiment 2a.

Stimuli were selected according to the same criteria as applied in Experiment 1, and intended to be as similar as possible. During the familiarisation phase infants heard four monosyllabic words with a final /t/ embedded in passages. The target words were all existing German nouns: *Glut* [gluːt], *Laut* [laʊt], *Schrot* [ʃroːt] and *Zeit* [tsaɪt]. We consulted ELFRA word lists (Grimm & Doil, 2000), the German analogue of the MacArthur CDI, to gauge familiarity of these items. Of our four test items, *Glut, Laut* and *Schrot* are not listed as being produced by 24-month-olds, and *Zeit* is reported as being produced by only 4.3% of 24-month-olds. We were reasonably certain that none of these words were familiar to 9-month-old infants. Items were embedded in passages that were translations of the Dutch passages used in Experiment 1. Passages had an average duration of 21.5 s, ranging from 20.9 s (*Schrot*) to 22 s (*Laut*). Acoustic details of the target words are presented in Tables 3a and 3b.

Infants heard a list of isolated plural forms of the target words inflected with *-e* or *-en* during the test phase: *Gluten* [gluːtən], *Laute* [laʊtə], *Schrote* [ʃroːtə] and *Zeiten* [tsaɪtən]. Each list contained 15 different tokens of each word and had an average duration of 25.1 s, ranging from 24 s (*Laute*) to 25.5 s (*Schrote*). Stimuli were recorded by a female native speaker in an infant-directed manner. All stimuli were deemed to sound natural by native speakers.

Experiment 2b.

In the same way as Experiment 1b, in this experiment infants were familiarised with monosyllabic words with a stem-final [t] deriving from an underlying /d/. During the test phase they heard plural forms of these stems with a word-medial [d]. The target items were: *Grad* [graːt], *Kleid* [klaɪt], *Schmied* [ʃmiːt] and *Tod* [toːt]. Again, all words are existing nouns that are unfamiliar to young children; none of these four words are present in the ELFRA list of productive vocabulary of 24-month-olds (Grimm & Doil, 2000). Target words were once more treated as nonce items and embedded in the same eight-sentence passages as Experiment 2a. Each passage had a duration of 25 s.

During the test phase infants heard lists of all four of these items in their plural form with a word-medial [d]: *Graden* [graːdən], *Kleider* [klaɪdɐ], *Schmiede* [ʃmiːdə] and *Tode* [toːdə]. Each list contained 15 different tokens of one item, and was 25 s long. Further acoustic details about all stimuli are presented in Tables 4a and 4b. The same native speaker as Experiment 2a recorded all stimuli in an infant directed manner.

Table 3a

Acoustic characteristics of the stimuli in Experiment 2a (mean values and SDs in parentheses).

		Duration (ms)	*Pitch (Hz)*	*Max Intensity (dB)*
Items in passages	*Glut*	426 (139)	279 (50)	76 (4)
	Laut	507 (82)	266 (67)	76 (4)
	Schrot	526 (150)	276 (67)	77 (4)
	Zeit	470 (116)	281 (47)	77 (4)
Items in lists	*Gluten*	943 (42)	308 (5)	81 (1)
	Laute	710 (32)	305 (6)	77 (2)
	Schrote	928 (69)	305 (4)	79 (2)
	Zeiten	880 (45)	301 (8)	76 (2)

Table 3b

Acoustic characteristics of syllables of stimuli in the test phase of Experiment 2a (mean values and SDs in parentheses).

	Duration (ms)		*Pitch (Hz)*		*Max Intensity (dB)*	
	1st syllable	*2nd syllable*	*1st syllable*	*2nd syllable*	*1st syllable*	*2nd syllable*
Gluten	430 (35)	514 (25)	308 (5)	219 (13)	81 (1)	72 (1)
Laute	371 (24)	339 (15)	305 (6)	206 (10)	77 (2)	68 (2)
Schrote	558 (52)	369 (30)	305 (4)	206 (10)	79 (2)	69 (2)
Zeiten	429 (26)	451 (32)	301 (9)	198 (9)	76 (2)	67 (1)

Table 4a

Acoustic characteristics of the stimuli in Experiment 2b (mean values and SDs in parentheses).

		Duration (ms)	*Pitch (Hz)*	*Max Intensity (dB)*
Items in passages	*Grad*	517 (129)	248 (71)	74 (7)
	Kleid	417 (128)	259 (54)	77 (5)
	Schmied	535 (159)	262 (49)	74 (4)
	Tod	509 (93)	272 (53)	74 (3)
Items in lists	*Graden*	806 (52)	288 (31)	76 (2)
	Kleider	677 (47)	300 (16)	77 (2)
	Schmiede	918 (67)	300 (19)	75 (2)
	Tode	814 (46)	299 (22)	77 (1)

Table 4b

Acoustic characteristics of syllables of stimuli in the test phase of Experiment 2b (mean values and SDs in parentheses).

	Duration (ms)		*Pitch (Hz)*		*Max Intensity (dB)*	
	1st syllable	*2nd syllable*	*1st syllable*	*2nd syllable*	*1st syllable*	*2nd syllable*
Graden	432 (41)	374 (23)	286 (35)	202 (12)	76 (2)	68 (1)
Kleider	399 (32)	278 (25)	297 (26)	243 (11)	77 (2)	71 (2)
Schmiede	606 (57)	312 (28)	300 (19)	213 (31)	75 (2)	71 (3)
Tode	462 (44)	351 (27)	294 (33)	228 (15)	77 (1)	70 (2)

Procedure and apparatus.

The design and procedure were identical to Experiment 1 with a few minor alterations due to differences in the lab situation. Firstly, the experiment was programmed and controlled using *NESU* (Baumann, Nagengast, & Klaas, 1993). Secondly, the experimenter was situated in a separate room from the infant, thus removing the need for the experimenter to wear headphones and listen to masking music in order to remain naïve to experimental condition. These differences were not expected to have an effect on infants' looking behaviour.

Half of the infants in Experiment 2a were familiarised on passages containing *Glut* and *Schrot*, and the other half on passages containing *Laut* and *Zeit*. In Experiment 2b half of the infants were familiarised on passages containing *Grad* and *Schmied* and half on passages containing *Kleid* and *Tod*.

Data preparation and analysis.

Looking behaviour was coded offline by an experienced coder using the software *SuperCoder* (Hollich, 2003). Coder reliability was judged by having a second experienced coder re-code data from 6 participants of each Experiment 2a and 2b (25% of participants). Reliability was very high for both measures of total look and longest look, with Pearson product-moment correlations of 0.99 ($p < .001$) in both Experiment 2a and 2b for the total looking measure and 0.97 ($p < .001$) for Experiment 2a and 0.96 ($p < .001$) for Experiment 2b using the longest look measure.

The same exclusion criteria were applied as in Experiment 1. Infants were excluded if they did not complete the test phase due to fussiness, for example crying (Experiment 2a = 3, Experiment 2b = 7). Of the data remaining, trials were excluded where the infant did not orientate to the target lamp for at least 1 s (Experiment 2a = 8 trials, Experiment 2b = 24 trials), or if they fixated on the lamp for the whole trial (Experiments 2a and 2b = 0 trials). Infants were removed if their average longest look to all remaining trials was shorter than 3 s (Experiment 2a = 2 participants, Experiment 2b = 2 participants), and if they had participated in fewer than seven of the twelve test trials (Experiment 2b = 1 participant). Remaining for analysis were data from 24 participants per experiment, each of whom had participated in at least 7 of 12 trials with a longest look of at least 1 s per trial.

Results and discussion

As in Experiment 1, in this experiment both total mean orientation times and mean longest looking times to each word across the three blocks in each experiment (2a and 2b) were measured. Orientation times were averaged for trials containing familiar or novel items and a two-way analysis of variance conducted with the within-subject factor Familiarity (familiar vs. novel trials), the between subject factor of Morphophonology (non-alternating vs. alternating) and the interaction of these two factors.

Considering first total orientation time data, our analysis revealed a marginally significant main effect of Familiarity, $F(1,46)=2.9$, $p=.097$. Infants had a tendency to listen longer to novel trials as opposed to familiar trials during the test phase. There was no main effect of Morphophonology, $F(1,46)=.35$, $p=.56$, and no interaction of Familiarity x Morphophonology, $F(1,46)=.602$, $p=.44$. Pairwise comparisons indicated that the novelty preference was driven by the non-alternating condition, where the effect of Familiarity was marginally significant, $F(1,22)=3.05$, $p=.087$. In this condition mean orientation time to familiar trials was 6.9 s (SD = 2.3) and to novel trials 7.87 s (SD = 2.2), with 15 of the 24 infants displaying a novelty preference. In the alternating condition, this effect did not approach significance, $F(1,22)=.423$, $p=.52$. In the alternating condition mean orientation time to familiar trials was 7.6 s (SD = 2.3) and to novel trials 8 s (SD = 3.1). Twelve infants listened longer to familiar trials, and twelve preferred to listen to novel trials.

Analysing infants' mean longest looks to familiar and novel trials, we found a similar pattern of results. In this analysis we found no main effect of Familiarity, $F(1,46)=1.784$, $p=.188$, and no main effect of Morphophonology, $F(1,46)=.037$, $p=.848$. The interaction of Familiarity and Morphophonology was marginally significant, $F(1,46)=3.375$, $p=.073$: infants tended to look more to novel than familiar trials. Pairwise comparisons again revealed that the effect was driven by the non-alternating condition. In the non-alternating condition there was a significant effect of Familiarity, $F(1,22)=5.033$, $p=.03$, with infants listening significantly longer to novel trials (mean = 5.46 s, *SD* = 1.7) than familiar trials (mean = 4.7, *SD* = 1.4). Sixteen infants displayed a preference for novel trials and eight for familiar trials. The effect of Familiarity in the alternating condition was not significant, $F(1,22) = .126$, $p = .72$, with ten infants displaying a novelty preference and fourteen a familiarity preference.

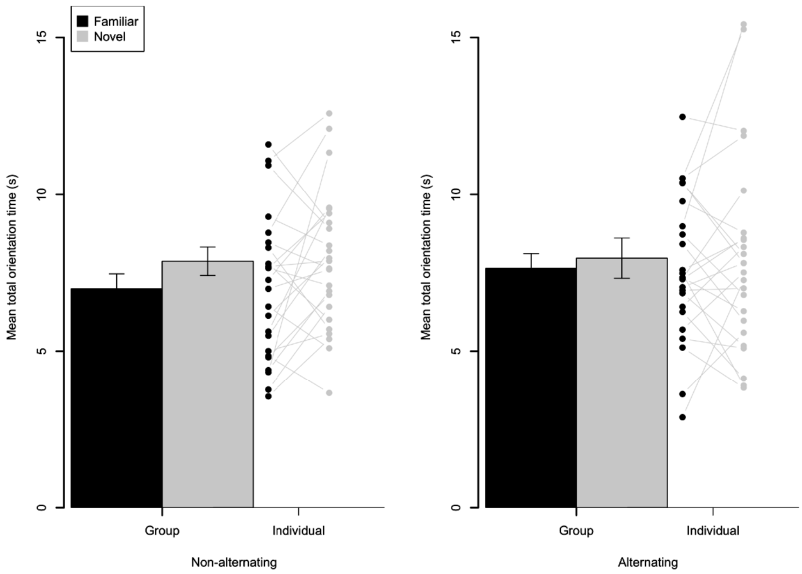

Figure 3a. Mean total orientation times (and SE of mean) to familiar and novel items during the test phase of Experiment 2a (non-alternating condition) and 2b (alternating condition).

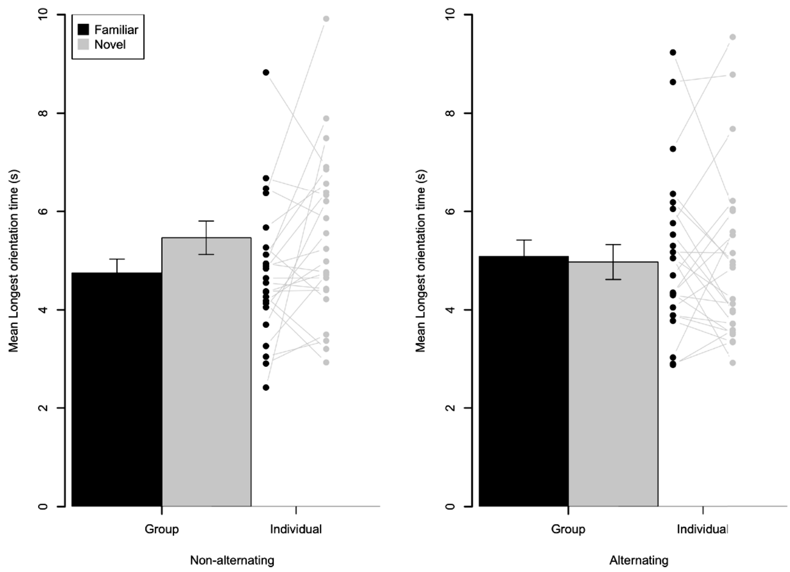

Figure 3b. Mean longest orientation times (and SE of mean) to familiar and novel items during the test phase of Experiment 2a (non-alternating condition) and 2b (alternating condition).

Results from Experiment 2 show that, as predicted, German-learning infants differentiated between novel and familiarised items in the non-alternating condition. This result further indicates that German 9-month-olds are able to segment and recognise words from connected speech (Höhle & Weissenborn, 2003; Jusczyk & Aslin, 1995; Jusczyk, Houston, et al., 1999). However, in the alternating condition they show no preference for either familiar or novel stimuli. That is, when familiarised with a monosyllabic, singular form, infants were able to recognise the plural of this stem when formed by affixation alone. If a voicing alternation also occurred between the stem and complex form, as in Experiment 2b, infants failed to recognise the familiarised form.

Our results are in keeping with the results of Marquis and Shi (2012), who established that preverbal infants are able to encode functional morphemes. We have shown, in a different language, that by nine months old, infants display sensitivity to the overlap in form of roots and inflected forms. This can be interpreted as sensitivity to the grammatical, rather than semantic, function of inflectional morphemes.

The results of Experiment 2b indicate that German learning 9-month-olds do not assign morphologically related forms to the same lexical item if suffixation of the inflectional affix also results in a voicing change. Similar to embedded words (e.g. ham~hamlet) in Jusczyk, Houston, et al. (1999), infants perceive *Grad* and *Graden* as different lexical items. If there is a change in voicing, German 9-month-olds do not treat the stem and inflected form as morphological variants but treat them as separate lexical items. From this we can deduce that at nine months old German infants are sensitive to voicing as a phonemically contrastive cue but not an allomorphic cue.

In contrast to some segmentation studies, we found that infants have a preference for novel rather than familiarised stimuli during the test phase. The infants in our study were older than those in many segmentation studies; Jusczyk and Aslin (1995) and Jusczyk, Houston, et al. (1999) both tested 7.5-month-olds and Höhle and Weissenborn (2003) 6-month-olds. The difference in the direction of the effect between previous studies and this study is consistent with a reported tendency for older infants to show a novelty preference and younger infants a familiarity preference (Cristia & Seidl, 2008; Houston-Price & Nakai, 2004; Seidl, Cristia, Bernard, & Onishi, 2009). Clearly this is not the only factor which determines the direction of the effect, as Jusczyk, Houston, et al. (1999) also tested 10.5-month-olds and Mattys and Jusczyk (2001) used a similar task with 9-month-olds. In both of these studies infants also displayed a familiarity preference. Whether one should predict a novelty or familiarity effect is an ongoing debate (cf. Houston-Price & Nakai, 2004) that warrants further discussion and investigation, however, this was not the primary interest of this study.

General Discussion

The goal of these experiments was twofold. Firstly, in Experiments 1a and 2a, we hypothesised that we would replicate the results of Marquis and Shi (2012) in showing that infants are sensitive to the high frequency and variability in inflectional suffixes, and are able to use this information to assign stems and inflected forms to the same lexical entry. We initially predicted that both Dutch and German infants would succeed in this task. Secondly, in Experiments 1b and 2b, we were interested in whether nine-month-olds display sensitivity to voicing alternations in the inflectional paradigm and if they are able to assign a stem and inflected form to the same lexical entry when a voicing alternation occurs alongside suffixation. We predicted differences between Dutch- and German-learning infants' behaviour in this condition would arise from cross-linguistic differences in the phonological and lexical systems of how, where and when the voicing contrast is realised.

We found that German infants (Exp. 2a) are, in line with previous studies and our predictions, able to segment words from fluent speech (Altvater-Mackensen & Mani, 2013; Höhle & Weissenborn, 2003; Jusczyk & Aslin, 1995; Jusczyk, Houston, et al., 1999). They display sensitivity to inflectional morphology and can assign roots and inflected forms to the same lexical entry (cf. Marquis & Shi, 2012). However, with the addition of a voicing alternation (Exp. 2b), they do not assign stems and affixed forms to the same lexical entry. At nine months old German infants are perceiving [t] and [d] as contrastive phonemes, and treating minimal pairs that differ only in the voicing specification of a segment as two separate lexical items. Indeed, this is a valid assumption on the part of the infant, as in most cases /t/ and /d/ are contrastive. During the second half of their first year their perceptual system undergoes substantial reorganisation, enabling them to identify and distinguish between acoustic contrasts that are linguistically relevant or irrelevant in their native language (Bortfeld et al., 2005; Houston & Jusczyk, 2000; Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Singh, White, & Morgan, 2008; Werker & Tees, 1984). Clearly voicing is a linguistically relevant contrast for German infants. Initially they learn that it constitutes a phonemic contrast and only later, once they have more knowledge of morphology and a lexicon, will they develop sensitivity to voicing alternations and learn that surface forms do not always match the underlying form.

Theoretical approaches to infants' acquisition of non-allophonic alternations (Hayes, 1999; Peperkamp & Dupoux, 2002; Tesar & Prince, 2003), of which the voicing alternation in Dutch and German is an example, propose that the learner must first learn how to segment words from speech and identify word boundaries. Once they can do this they will be able to use the distribution of voicing to infer that the voicing contrast must be neutralised in final position, and later, with additional morphological and semantic knowledge, they can deduce in which lexical items this neutralisation occurs (i.e. which morphological paradigms contain a voicing alternation). Our data indicate that German 9-month-olds have segmentation abilities in place but do not have the required skills or knowledge to posit intraparadigmatic links between forms that differ in surface voicing.

This theoretical outline relates to the question of which cues infants initially use to segment speech, and at what point. Peperkamp and Dupoux (2002) and Tesar and Prince (2004) predict that segmentation skills, the details of which are not specified, will precede sensitivity to distributional cues. However, experimental studies show that infants use precisely this distributional information to help them segment speech and identify word boundaries (Johnson & Jusczyk, 2001; Saffran et al., 1996). For example, Mattys et al. (1999) and Mattys and Jusczyk (2001) found that 9-month-olds are sensitive to the frequency of occurrence of segments within clusters, distinguishing “within-word” and “between-word” sequences and using these to posit word boundaries. In the case of final devoicing, one could predict that infants could use the absence of voicing in word final position as a cue to the location of word boundaries; if a voiced obstruent is encountered a word boundary cannot have been reached. There are a number of possible explanations for this circularity problem. On the one hand, assuming that infants only use the speech stream itself (i.e. bottom-up processing), they have more cues at their disposal in natural speech than distributional information alone. Despite accomplished use of statistical cues, when these conflict with other cues present in natural speech such as stress or coarticulation, infants utilise speech cues over distributional cues (Johnson & Jusczyk, 2001; Mattys et al., 1999). In addition, Adriaans and Kager (2010) successfully demonstrated a computational model that is most successful in learning phonotactics if both segmentation and generalisation are incorporated. An alternative view, proposed by Martin, Peperkamp and Dupoux (2013) and Feldman, Griffiths and Morgan (2009), proposes that infants create a proto-lexicon and use this top-down knowledge to supplement their exploitation of input cues. Either of these accounts could explain how infants can initially segment speech and identify word boundaries, before making the generalisation that there is no voicing contrast word-finally. Further evidence for this ordering of cue sensitivity was presented by Jusczyk, Hohne and Bauman (1999) who found that nine month old English-learning infants can segment words from speech, but do not use allophonic cues to word boundaries (e.g. *night rates* vs. *nitrates*) until 10.5 months of age. We conclude that although nine-month-old German infants can segment speech, they cannot yet use the distribution of the voicing contrast to their advantage. Repeating this experiment with older infants would allow us to identify the age at which this ability arises.

Counter to our hypotheses, Dutch infants did not display a difference in their orientation times to familiar or novel items in the non-alternating condition, indicating a lack of recognition of the inflected form of familiarised forms. Although the original segmentation studies of Jusczyk and colleagues demonstrated that American 7.5-month-olds can segment words from fluent speech (e.g. Jusczyk & Aslin, 1995; Jusczyk, Houston, et al., 1999), subsequent research has shown that for Dutch infants this ability is first visible using behavioural paradigms at nine months of age (Houston et al., 2000; Kuijpers et al., 1998). Dutch infants show evidence of segmentation abilities at seven months old, but this is only visible in electrophysical paradigms where no overt response is required from the infant (Junge, Hagoort, Kooijman, & Cutler, 2010; Kooijman et al., 2008; Kooijman, Junge, Johnson, Hagoort, & Cutler, 2013). We assume that Dutch nine-month-olds are able to segment words from speech, and their failure to show a preference in Experiment 1a results from their inability to identify stems and inflectionally related forms to the same lexical entry. They instead treat related forms as separate lexical entries (Jusczyk, Houston, et al., 1999) In light of this result it is not surprising that they show no preference in Experiment 1b, in the presence of voicing alternations.

The interesting question lies in why we find a difference between Dutch and German infants' abilities in these experiments. We hypothesised that cross-linguistic differences would emerge in Experiments 1b and 2b, and could be attributed to linguistic factors, notably differences between the phonological systems. However, this hypothesis cannot be confirmed, as Dutch infants did not succeed in the non-alternating condition of Experiment 1a. We nevertheless believe that differences between Dutch and German infants' behaviour are attributable to linguistic factors. By "linguistic factors" we here refer to the knowledge that infants had before participating in this experiment, that is, their experience with, and knowledge of, the properties of their native language. This can be contrasted with another source of variation present, namely the experience that infants built up during the experiment; the influence of the laboratory setting, acoustic properties of the stimuli recordings or selection of stimuli items on infants' behaviour. We first discuss the experimental factors and then the linguistic factors.

In terms of laboratory setting, one could argue that Experiments 1 and 2 were conducted in different laboratories and that this may bear on our results. Considering that both Nijmegen and Potsdam baby labs have successfully conducted segmentation studies in the past we assume that location differences did not crucially determine our results.

Secondly, the acoustic properties of the stimuli may have affected infants' behaviour. We compared differences in the intonation contour of our stimuli, as this is a salient feature of child directed speech that infants are known to respond positively to (Fernald & Simon, 1984; Fernald et al., 1989; Grieser & Kuhl, 1988; Masataka, 1992). Comparing the pitch range of all tokens used in the test phase of Experiments 1a and 2a, the non-alternating conditions of both languages, revealed a slightly larger pitch range in the German stimuli than the Dutch stimuli (German: $M = 169$ Hz, $SD = 20$; Dutch: $M = 147$ Hz, $SD = 23$). This difference is marginally significant, $F(1,1) = 3.4$, $p = .07$. We do not expect this difference to be large enough to adversely influence infants' behaviour, however, we cannot fully rule this out.

With regard to the choice of stimuli items, there were two differences that were impossible to avoid when selecting existing words: Firstly, the presence of complex onset clusters, and secondly, syllabification of the bisyllabic forms. In both Experiments 2a and 2b, three of the four tokens used in Experiment 2a had an onset cluster (2a: [gl], [ʃr], [ts],[l], 2b: [gr], [kl], [ʃ], [t]) and, whereas all of the Dutch tokens had a simplex onset (1a: [d], [m], [p], [ʋ], 1b: [m], [p], [t], [ʋ]). Clusters are more acoustically salient than simple onsets (Mattys & Jusczyk, 2001), possibly making the German stimuli more interesting to infants than the Dutch stimuli. Infants may find it easier to build and retain a representation of more interesting items for the duration of the experiment, aiding mapping during the test phase. On the other hand, the presence of clusters may work against German infants. It is known that onset clusters are difficult to acquire in production (see McLeod and van Doorn, 2001, for review). Although the exact nature of the relationship between early perception and production abilities remains unclear, Levelt (2012) found evidence for a link between children's inability to parse marked structures and difficulty in producing them. This argument would predict that German infants should have more difficulty parsing the complex syllable onsets, making the task more challenging for them than the Dutch participants. Onset clusters also play a role in segmentation of words from speech as they provide phonotactic cues which infants can use to identify word boundaries (cf. Mattys & Jusczyk, 2001). However, in the Dutch passages the segment before the onset of the target word was either a vowel or nasal, which would create an illegal onset cluster if segmented with the onset of the target word. Thus, in this sense German infants were not provided with an undue advantage as both groups of participants were provided with similar phonotactic cues for the presence of a word boundary preceding the target word. In addition, if German infants' superior segmentation ability in this task was attributable to the presence of an onset cluster, it may be predicted that they would have performed better in Experiment 2b.

Syllable structure and syllabification of the stem-final obstruent in bisyllabic plural tokens differed between the two languages' stimuli sets. All Dutch stems contained a short (lax) vowel, whereas the German stems contained a long vowel or diphthong. Syllabification in both languages is argued to follow the principle of onset maximisation, with neither language permitting a syllable to end in a short lax vowel (Dutch: Booij, 1995; German: Wiese, 1996). The long vowels or diphthongs in the German stimuli form an acceptable syllable, and accordingly, the stem-final obstruent in these tokens will be resyllabified into the onset of the second syllable. For example, *Gluten* will be syllabified as [gluː.tən], with a conflict between syllabic and morphological segmentation; *Glut-en*. The short lax vowel of the Dutch stems does not constitute a fully formed syllable, raising the question of how the inter-vocalic [t] will be syllabified. One theory proposes that the medial /t/ will be ambisyllabic [dɔt̥ən] (van der Hulst, 1985), and experimental evidence supports this claim; Dutch adults perceive a word-medial, intervocalic obstruent as closing the first syllable (Zwitserlood, Schriefers, Lahiri, & Van Donselaar, 1993). For the Dutch infants the CVC structure of the stem overlaps fully with the first syllable of the inflected form; there is great phonological overlap between the stem and inflected form, and no conflict between the outcomes of syllabic or morphological segmentation. For German infants the first syllable is CVV, with the stem-final C belonging to the second syllable. If Dutch infants were using the same strategy as Dutch adults in their syllabic segmentation the differences between Dutch and German stimuli would potentially favour the Dutch infants in our task. However, Shi and Marquis (2009) showed that when syllabic and morphological cues conflict infants favour a morphological segmentation strategy over syllabic parsing.

Turning to linguistic differences that do not relate to the specific stimuli used or experimental environment, we originally hypothesised that the predominant factor would be differences in the phonological system of the languages, specifically the functional load of the voicing contrast in each language. Although contrastive in both languages, voicing is a more reliable cue in German than in Dutch. This hypothesis was most relevant for predicting differences in infants' sensitivity to voicing alternations (Experiments 1b and 2b), yet we found no difference between Dutch and German infants' sensitivity to morphophonological alternations in morphologically complex forms; if there is a voicing alternation between the stem and inflected form, infants from both language groups treat these two forms as separate lexical items. We did, however, find differences between Dutch and German infants' sensitivity to suffixation without voicing alternations, which cannot solely be attributed to differences in the phonology of voicing.

One possible source of this difference stems not from differences in infants' inflectional knowledge, but more generally from differences in their segmentation abilities, driven by other properties of the language. It has previously been found that Dutch infants lag approximately one month behind English learning infants in their ability to segment bisyllabic words from speech (Jusczyk, Houston, et al., 1999; Kuijpers et al., 1998). Cutler, (2012) proposes that the different degree of vowel reduction in the two languages affects listeners' ability to make use of stress cues for segmenting speech and is therefore responsible for this delay. The predominant stress pattern in Dutch, English and German is trochaic, or strong-weak, and by nine months of age infants are sensitive to this pattern (Jusczyk, Cutler, & Redanz, 1993; Morgan & Saffran, 1995) and use it as a segmentation cue (Echols et al., 1997; Johnson & Jusczyk, 2001; Jusczyk, Houston, et al., 1999; Morgan & Saffran, 1995). Cutler (2012) argues that English has more vowel reduction than Dutch; vowels in an unstressed syllable following a stressed syllable will be reduced to schwa in English, but not in Dutch[3]. The acoustic difference between strong and weak syllables is increased in English making stress-based segmentation easier for English infants. Vowel reduction in German is less pronounced than in English, with vowels in unstressed syllables being somewhat reduced and centralised but not to the same extent (Delattre, 1969). However, there is a difference in how weak, schwa syllables and function elements are reduced in Dutch and German. German function words are highly reduced (Kohler, 1990), as are schwa syllables (Kohler & Rodgers, 2001). Consider the German stimuli item *Gluten*, which may be pronounced with (almost) no vowel at all [gluːtn̩]. A comparable form such as *dotten* in Dutch would retain the schwa of the second syllable (though delete the final *n*). Although stress-based, vowel reductions are not necessarily significantly different in Dutch and German syllables with a canonical full vowel, in schwa syllables this distinction is greater. Additionally, the complex inflectional system of German exposes infants to many inflected words suffixed with a schwa syllable. This extensive inflectional marking, together with the stress-based cues, may provide German infants with more accomplished segmentation abilities than Dutch infants. Once they have established segmentation strategies they are in a stronger position to be able to focus on other elements of the speech-stream, such as content and distributional regularities.

An extensive inflectional system also provides German infants with a great deal of variation in the acoustic form of the second (weak) syllable. Taking nominal inflections as an example, there are five plural suffixes in German; *-e* [ə], *-er* [ɐ], *-n/en* [(ə)n], *-s* [s] or no overt suffix, compared to only two in Dutch *-en* [ə(n)] and *–s* [s]. In addition, German stems taking *-e, -er* or no overt suffix may also umlaut the stem vowel. Verbs and adjectives also obligatorily mark case, gender and number. In order to be grammatical many words in German end in an inflectional affix. There is a high degree of variability in the exact acoustic form

[3] The first two syllables of the Dutch words *oktober* and *octopus* differ only in stress, and not vowel quality with both being [okto]. Compare this to the English cognates, where the second syllable of *octopus* in English is reduced to schwa (Cutler, 2012, p. 24)

of this affix and the grammatical and phonological properties of the words and segments it may affix to. So much variation within the inflectional system could be seen as a disadvantage for the German infant, as they are presented with so many different suffixes that they struggle to identify the prevailing pattern. However, Shi et al., (2006) showed that at eight months old English-learning infants have an acoustically underspecified representation of prosodically weak functor units. For German infants this would predict that although they are faced with a high degree of variation in the inflectional system, at this point in their development they gloss over the fine acoustic differences between the forms. They perceive, and form representations of, the final syllables of complex words but do not specify whether it is [ə], [ɐ] or [ən] etc. In this way German infants use the stress cues of inflected words to help them segment forms, but they reduce the perceived variability in their input by treating all inflectional suffixes as equal. The high frequency and variability of inflectional suffixes facilitates sensitivity to their status as function elements in the child's developing lexicon. With this knowledge infants are able to assign stems and affixes to the same lexical entry. In our task we included *-en*, *-er,* and *-e* suffixes and infants performed equally well in all types, further supporting this interpretation.

A counter argument to this interpretation could be found in Marquis and Shi (2012), where they demonstrated that French 11-month-olds distinguish between existing and novel suffixes, thereby suggesting that they do not have an underspecified representation of functional elements. There are two responses to this argument. Firstly, underspecification of functional elements is a developmental stage that infants quickly pass through. Whereas the eight-month-olds in Shi et al.'s (2006) study were insensitive to changes in acoustic form, 11-month-olds (i.e. the same age as the participants in Marquis and Shi's 2012 study), displayed sensitivity to changes, and therefore evidence for fine-grained acoustic specificity. Secondly, there is a prosodic difference between French and German stress assignment. Whereas function units in final-position are unstressed and reduced in German, in French they receive stress. Stress is non-contrastive in French, falling on the last syllable of a word, even when this is an inflectional morpheme. The underspecification of form hypothesis applies to prosodically weak functor units (Shi et al., 2006). A suffix that has a full vowel and receives primary stress will be more salient and therefore more likely to have a specified representation, ensuring that French infants are sensitive to the specific acoustic form of a suffix.

Our data show, however, that German infants are paying attention to the acoustic form of the syllable containing the suffix as they were sensitive to the voicing alternation between the stem and plural form in Experiment 2b. As previously discussed, the stem-final obstruent in our stimuli would always be resyllabified into the onset of the second syllable; *Glu.ten* and *Gra.den*. It seems that underspecification of functor units only extends to the suffix itself, and not the whole syllable that the functor appears in. Infants were sensitive to the difference between [tən] and [dən], but tracked that the plosive belonged to the stem and not the affix. The affix is an onsetless, prosodically weak, suffix. Similar to Shi and Marquis (2009), German infants are sensitive to differences between morphological or syllabic segmentation and where there is conflict they use a morphological segmentation strategy.

This morphological segmentation interpretation assumes that infants are conducting, at least at a basic level, some morphological analysis of input forms. Children are known to have difficulty in tasks that require morpheme stripping (Van de Vijver & Baer-Henney, 2011; Zamuner, Kerkhoff, & Fikkert, 2011). Because children find morpheme-stripping tasks difficult does not necessarily mean they are not participating in any form of morphological analysis. For example, children typically mark plurality in known words from about 20 months of age (Bittner & Köpke, 2001; Cazden, 1968; de Villiers & de Villiers, 1972), and can generalise this knowledge to novel forms by four years old (Berko, 1958; Kerkhoff & De Bree, 2005; Van de Vijver & Baer-Henney, 2011), indicating some degree of morphological analysis and knowledge of paradigmatic relationships. The infants who participated in our study lacked the semantic knowledge to conduct a morphological analysis in this sense. By nine months old infants are becoming language specific listeners, and making use of the acoustic cues that are important for developing speech and language abilities in their native language. We have shown that the German infants are able to make use of the prosodic cues to inflectional morphology, forming a precursor to morphology proper, that Dutch infants are not yet sensitive to.

Appendix I

Familiarisation passages, Experiments 1a & 1b (Dutch)

Infants were familiarised to *dot* and *mat* or *pit* and *wet* in Experiment 1a, and to *tod* and *mud* or *pad* and *wed* in Experiment 1b.

Dot / Pad

Deze *dot / pad* was uit een boom gevallen.
This X fell out of a tree.
Dit is een *dot / pad.*
This is an X.
De *dot / pad* is zacht.
The X is soft.
Kijk, een *dot / pad.*
Look, an X.
De *dot / pad* zal ik nooit alleen laten.
I will never leave the X on its own.
Ik heb mijn vader de *dot / pad* gegeven.
I gave my father the X.
Deze *dot / pad* is de mooiste die hij gezien had.
This X is the most beautiful he's seen.
Ik deel graag mijn *dot / pad.*
I gladly share my X.

Mat / Mud

Deze *mat / mud* is van onze buurman.
This X is from our neighbour.
Dit is een *mat / mud.*
This is an X.
De *mat / mud* is mooi.
The X is pretty.
Kijk, een *mat / mud.*
Look, an X.
De *mat / mud* is erg leuk om te knuffelen.
The X is nice to cuddle.
Ik heb een foto van de *mat / mud* gemaakt.
I took a photo of the X.
Die *mat / mud* was de beste die wij ooit hebben gehad.
The X was the best we'd ever had.
Ik houd van de *mat / mud.*
I love the X.

Pit / Tod

Deze *pit / tod* heeft mijn moeder gekocht.
My mother bought this X.

Dit is een *pit / tod.*
This is a X.

De *pit / tod* is groot.
The X is big.

Kijk, een *pit / tod.*
Look, a X.

De *pit / tod* lijkt een beetje op een rups.
The X looks like a caterpillar.

Gisteren heb ik met de *pit / tod* gespeeld.
Yesterday I played with the X.

De *pit / tod* is erg leuk om mee te spelen.
It is fun to play with the X.

Ik ben blij met mijn *pit / tod.*
I'm happy with my X.

Wet / Wed

Deze *wet / wed* heb ik gevonden.
I found this X.

Dit is een *wet / wed.*
This is a X.

De *wet / wed* is lief.
The X is nice.

Kijk, een *wet / wed.*
Look, a X.

De *wet / wed* en ik gaan samen naar bed.
I go to bed with my X.

Ik heb een plaatje van de *wet / wed* getekend.
I drew a picture of the X.

De *wet / wed* en ik zijn altijd samen.
The X and I are always together.

Ik ben blij met de *wet / wed.*
I'm happy with my X.

Appendix II

Familiarisation passages, Experiments 2a & 2b (German)

Infants were familiarised to *Glut* and *Schrot* or *Laut* and *Zeit* in Experiment 2a, and to *Grad* and *Schmied* or *Kleid* and *Tod* in Experiment 2b.

Glut / Grad

Diese Glut / Diesen Grad habe ich gefunden.
I found this *X*.
Das ist ein(e) *Glut / Grad.*
This is a *X*.
Die Glut / Der Grad ist lieb.
The *X* is nice.
Schau mal, *eine Glut/ ein Grad.*
Look, a *X*.
Die Glut / Der Grad und ich gehen zusammen ins Bett.
I go to bed with my *X*.
Ich habe ein Bild von *der Glut / dem Grad* gemalt.
I drew a picture of the *X*.
Die Glut / Der Grad und ich sind immer zusammen.
The *X* and I are always together.
Ich bin glücklich mit *meiner Glut / meinem Grad.*
I'm happy with my *X*.

Schrot / Schmied

Diesen *Schrot / Schmied* hat meine Mutter gekauft.
My mother bought this X.
Das ist ein *Schrot / Schmied.*
This is a X.
Der *Schrot / Schmied* ist groß.
The X is big.
Schau mal, ein *Schrot / Schmied.*
Look, a X.
Der *Schrot / Schmied* sieht aus wie eine Raupe.
The X looks like a caterpillar.
Gestern habe ich mit dem *Schrot / Schmied* gespielt.
Yesterday I played with the X.
Der *Schrot / Schmied* ist wirklich super zum Spielen.
It is fun to play with the X.
Ich bin glücklich mit meinem *Schrot / Schmied.*
I'm happy with my X.

Laut / Tod

Dieser Laut / Diese Tod ist aus einem Baum gefallen.

This *X* fell out of a tree.

Das ist ein *Laut / Tod.*

This is a *X.*

Der *Laut / Tod* ist weich.

The *X* is soft.

Schau mal, ein *Laut / Tod.*

Look, a *X.*

Den Laut / Tod werde ich nie allein lassen.

I will never leave the *X* on its own.

Ich schenkte meinem Vater *den Laut / dem Tod.*

I gave my father the *X.*

Dieser Laut / Diese Tod ist der schönste, *den/das* er gesehen hatte.

This *X* is the most beautiful he's ever seen.

Ich teile gerne meinen *Laut / Tod.*

I gladly share my *X.*

Zeit / Kleid

Diese Zeit / Dieses Kleid ist von unsere Nachbarn.

This *X* is from our neighbour.

Das ist *eine Zeit / ein Kleid.*

This is a *X.*

Die Zeit / Das Kleid ist schön.

The *X* is pretty.

Schau mal, *eine Zeit / ein Kleid.*

Look, a *X.*

Die Zeit / Das Kleid ist sehr gut, um zu kuscheln.

The *X* is nice to cuddle.

Ich habe ein Foto von *der Zeit / dem Kleid* gemacht.

I took a photo of the *X.*

Die Zeit / Das Kleid war die beste, die wir je gehabt hatten.

The *X* was the best we'd ever had.

Ich liebe *die Zeit / das Kleid.*

I love the *X.*

3

Dutch and German 3-year-olds' representations of voicing alternations[1]

Introduction

Spoken language, even infant and child directed speech, rarely features words in isolation (Aslin, Woodward, LaMendola, & Bever, 1993). Most utterances are multi-word utterances where boundaries between words are often unclear. Moreover, even words in isolation are seldom monomorphemic. Many words require inflectional morphology in order to be grammatical. Combining affixes and words frequently gives rise to phonological processes linked to language-specific phonotactic restrictions which may lead to changes in the phonetic form of the stem or morpheme, also known as morphophonological alternations. While the acquisition of language-specific phonotactics (e.g. Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993; Mattys & Jusczyk, 2001), and the acquisition of inflectional morphology (e.g. Cazden, 1968; Clahsen, Rothweiler, Woest, & Marcus, 1992; Mervis & Johnson, 1991) have often been studied, there has been little research into the interface of these two domains. Morphophonological alternations are acknowledged as being one of the most cognitively complex processes to acquire, with acquisition not being achieved until adolescence (Kiparsky & Menn, 1977; Pierrehumbert, 2003). Despite the long history of this observation there has been little experimental investigation into the acquisition of these processes. Existing papers on the acquisition of morphophonological alternations have primarily been interested in children's

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[1] A version of this paper has been submitted for publication

productions, and their ability to generalise alternation patterns to novel forms (Kerkhoff, 2007; Van de Vijver & Baer-Henney, 2011; Van Wijk, 2007; Zamuner, Kerkhoff, & Fikkert, 2011), using methods based on Berko (1958). In this paper we use a perception-based task to investigate how morphophonological alternations are represented in the toddler's mental lexicon. The precise combination of a phonotactic constraint and its interaction with morphophonology is language-specific, however, similar patterns are attested in multiple languages providing opportunity to tease apart the role of cognitive development and language-specific effects. For this reason we investigate acquisition of the same voicing alternation by learners of two languages; Dutch and German.

Both Dutch and German have a two-way voicing contrast between voiced and voiceless obstruents[2]. Both voiced and voiceless obstruents occur in onset and medial positions, but only voiceless obstruents are permitted syllable- or word-finally. Underlyingly voiced obstruents will be realised as voiceless in this position.

Table 1

The voicing contrast in Dutch and German.

		Initial			*Medial*			*Final*		
Dutch	/t/	[tak]	*tak*	'branch'	[kɛtɪŋ]	*ketting*	'necklace'	[pɛt]	*pet*	'cap'
	/d/	[dak]	*dak*	'roof'	[lɑdər]	*ladder*	'ladder'	[bɛt]	*bed*	'bed'
German	/t/	[taɪç]	*Teich*	'pond'	[bɔʏtl̩]	*Beutel*	'bag'	[broːt]	*Brot*	'bread'
	/d/	[dax]	*Dach*	'roof'	[feːdɐ]	*Feder*	'feather'	[hʊnt]	*Hund*	'dog'

Alternations within a morphological paradigm arise when a vowel-initial suffix is affixed to a stem with a final (underlyingly) voiced obstruent. The stem-final obstruent is no longer in syllable-final position and is not subject to devoicing. Stem-final, underlyingly voiceless obstruents do not participate in

[2] Whether one refers to a laryngeal or a voicing contrast is dependent on beliefs about the contrast in aspirating languages with no phonetic voicing. In this paper, while acknowledging this debate in the literature, we do not address it further and refer to the contrast at the phonemic level between 'voiced' and 'voiceless' (see Jansen, 2004; Jessen, 1998).

alternations and are voiceless throughout the morphological paradigm. Contrast the Dutch singular forms *bed* [bɛt] and *pet* [pɛt] with their plural forms *bedden* [bɛdən] and *petten* [pɛtən]. Neutralisation of voicing word-finally is a phonotactic constraint that occurs across the lexicon without regard for factors such as word-class or affix type. In this paper we focus on voicing alternations in singular-plural noun pairs.

The traditional account for voicing alternations is that underlyingly voiced obstruents are devoiced in positions where voicing is phonotactically illegal (Dutch: Booij, 1995; German: Wiese, 1996). This explanation assumes that speakers possess an underlying representation different to the surface form, and they must implement some sort of mechanism, for example rules or constraints, to link the two forms (cf. SPE, Chomsky & Halle, 1968 or Lexical Phonology, Kiparsky, 1982). In comprehension, listeners must reverse, or undo, the effects of final devoicing (Gaskell & Marslen-Wilson, 1996; Lahiri & Marslen-Wilson, 1990). When listening to speech all complex words will be parsed into constituent morphemes.

At the other end of the spectrum full listing models propose that speakers represent the surface form in their mental lexicon and not abstract representations. Proponents of usage-based (e.g. Bybee, 2001) or connectionist (e.g. Rumelhart & McClelland, 1986) models claim that rules, such as a rule of final devoicing, are useful descriptions of generalisations but just because the voicing contrast is neutralised word-finally in Dutch and German this need not imply that the mental lexicon contains an underlying representation that is voiced. It is argued instead that speakers represent surface forms in their lexicon, e.g., [bɛt] and [bɛdən].

A third group of theories are hybrids of the previous two, acknowledging that both decomposition and whole-form storage are possible (Baayen, Dijkstra, & Schreuder, 1997; Caramazza, Laudanna, & Romani, 1988; Clahsen, 1999; W. J. Levelt, Roelofs, & Meyer, 1999; Marcus, 1995; Pinker, 1991). In its strongest form, irregular inflections are stored as non-decomposable whole-word units, and regular forms are (de)composed from stems and affixes (Clahsen, 1999; Marcus, 1995). More recent evidence suggests that such a strict division of regular and irregular forms is unlikely; both full-form access and parsing are possible and highly frequent regular forms and forms where there is less form overlap between the stem and complex form are also likely to have a whole-form entry (Baayen et al., 1997; Baayen, McQueen, Dijkstra, & Schreuder, 2003). These models have predominantly been based on the case of the past-tense in English, arguing that regular verbs take the suffix *-ed*; the stem <walk> is selected from the lexicon, and the tense marker *-ed* is added *walked*. Irregular items involve suppletion of forms, e.g. *go~went*, or vowel changes, e.g. *run~ran*, with both the present and past tense forms having their own lexical representation.

We hypothesised that children make use of both mechanisms when acquiring a lexicon. They store both representations of complex forms, initially without any analysis of morphological complexity, and they are also able to form generalisations of how complex forms are regularly formed. It is our assumption that morphological paradigms containing a voicing alternation are likely to have a full form entry for the learner, as they cannot be formed by suffixation alone. Production data from both Dutch and German children supports the notion that voicing alternations are in some way "irregular". In productions of real words children frequently omit voicing, for example pronouncing *bedden* as [bɛtən], they fail to generalise voicing alternations to novel forms in wug-test tasks, and they have difficulty in undoing voicing alternations between plural and singular forms (reverse wug-test) (Kerkhoff, 2007; Van de Vijver & Baer-Henney, 2011; Van Wijk, 2007; Zamuner et al., 2011).

On the basis of production data alone, particularly for adult speakers, it is difficult to differentiate between an account that relies on abstract underlying representations or usage-based models (Zamuner et al., 2011). If a speaker correctly produces alternations in *bed* and *bedden* it is impossible to ascertain whether they have a correct underlying representation of the word-final /d/ and apply rules of final devoicing and pluralisation, or whether they have stored representations of the specific lexical item in both the singular and plural with no need for an abstract underlying representation.

Eliciting production data from children is also subject to task and articulatory demands. Requiring an overt response from the child requires a willingness to cooperate and lack of shyness on their behalf (cf. Mills & Neville, 1997). In addition, it is unclear whether children's inaccurate productions result from representational or articulatory deficits. On the one hand it could be that children's lexical representations are immature, and their production abilities are an accurate reflection of their lexical representation (cf. Ferguson & Farwell, 1975; Fikkert, 2010; Vihman & Croft, 2007). On the other hand, children's lexical representations may be fully specified, but inaccuracies arise due to immature articulatory control, or difficulties mapping representations to articulatory gestures (cf. Inkelas & Rose, 2007; MacNeilage & Davis, 2000; Pierrehumbert, 2003).

For the above-mentioned reasons we used a perception task in this study. In this paper we present results from a study with Dutch and German 3-year-olds. We compared the two languages because, despite them both having a similar voicing alternation, there are also a number of language-specific factors which may play a role in the acquisition process. By comparing learners of both languages we can further determine the relative contribution of language-general and language-specific factors on acquisition. Two predictors of ease of acquisition will be discussed in relation to Dutch and German; the phonological system and lexical frequency.

Differences between the phonological systems of Dutch and German, specifically those differences that relate to the voicing contrast, will be relevant for the acquisition of voicing alternations. Firstly, the reliability and variability of the voicing contrast in each language differs. Neutralisation of the voicing contrast syllable- and word-finally is a phonotactic constraint that applies across the whole class of obstruents. According to Clements' (2003) theory of feature economy, German uses voicing to maximal effect, maintaining a voicing contrast for labial, alveolar and velar plosives, and labiodental and alveolar fricatives (/p/-/b/, /t/-/d/, /k/-/g/, /f/-/v/, /s/-/z/)[3]. When any of these obstruents occur word- or syllable-finally the voiceless counterpart will surface. Voicing in Dutch is more restricted, for example, the contrast is less relevant for fricatives. There are very few minimal word-pairs that differ only in the [voice]-specification of the fricative, and intervocalically fricative voicing is largely allophonic; voiceless fricatives follow short vowels and voiced fricatives follow long vowels. Word-initially the voicing contrast of fricatives has been lost in many regions of the Netherlands, and all fricatives are produced as voiceless (Ernestus, 2000; van de Velde, Gerritsen, & van Hout, 1996). With regard to plosives, /g/ is not a native phoneme of Dutch (though it does appear in a few loan words, e.g., *buggy, goal*) so there is minimal use made of the voicing contrast in velar plosives. Finally, there are very few

[3] Note that /s/ and /z/ are not contrastive word initially.

items with a final /b/, minimising morphological paradigms with a labial plosive voicing alternation. Consequently, Dutch learners must glean nearly all of their knowledge about voicing alternations from the alveolar plosives /t/ and /d/. German children on the other hand receive evidence from the whole class of obstruents.

The second cross-linguistic difference in the phonological systems is in the complexity of voicing assimilation patterns. Although both Dutch and German display voicing assimilation across word and morpheme boundaries, Dutch voicing assimilation is arguably more complex because it is either progressive or regressive, depending on the manner of articulation. In German only progressive voicing assimilation is commonly attested. Booij (1995) describes two assimilation rules at play in Dutch: (1) before a voiced stop voiceless obstruents will be voiced, e.g., *voetbal* 'football' /tb/ will be realised as [db] due to regressive voicing assimilation. (2) Following a voiceless obstruent a voiced fricative will be devoiced, e.g., *opvallend* 'remarkable' /pv/ becomes [pf] due to progressive (de)voicing assimilation. Analysis of spontaneous speech corpora has indicated that this assimilation pattern is frequently attested, though not as strictly adhered to as previously believed (Ernestus, Lahey, Verhees, & Baayen, 2006), thereby adding further variation to the child's input. German predominantly displays progressive devoicing assimilation; following a voiceless obstruent, voiced plosives will be devoiced, e.g., *wegbringen* /kb/ becomes [kp] (Kohler, 1977). Thus, when a word-final voiceless obstruent is followed by an initial voiced obstruent, in German progressive devoicing occurs, but in Dutch the speaker must also track manner of articulation as this determines the direction of the assimilation.

The third cross-linguistic difference concerns other phonological alternations. Dutch has an optional alternation between /d/ and [j] or [ʋ]. For example, *rode* 'red' may be pronounced [rodə] or [rojə], and *oude* may be [ɔudə] or [ɔuʋə] (Booij, 1995). This alternation occurs in adjectives and verbs, but not nouns. Whether or not this alternation will impact on Dutch learners' acquisition of voicing alternations is dependent upon whether children are sensitive to the word-class restriction. German also has an additional alternation on obstruents, namely between /g/ and [ç] following [ɪ], e.g., *König* 'king', [køːnɪç]. The limited context of this alternation leads us to believe that it is likely to be less disruptive to acquisition of the voicing alternation than the Dutch /d/~glide alternation.

These differences between the phonological systems of the two languages suggest that German learning children may have an advantage over their Dutch peers when learning about voicing alternations. Voicing is not a reliable or robust cue in Dutch, and it is possible that Dutch learners pay little attention to it (cf. Warner, Smits, McQueen, & Cutler, 2005). German children have more experience with alternations because they encounter them across the whole class of obstruents, assimilation processes are clearer because assimilation goes in one direction only, and evidence for a voicing alternation is not masked by a conflicting alternation.

Corpus analysis of voicing alternations in Dutch and German child-directed speech

Alongside differences in the phonological systems of Dutch and German, there are also differences in lexical frequency of voicing alternations. Corpus studies of voicing alternations in Dutch and German have previously been published (Kerkhoff, 2007; Van de Vijver & Baer-Henney, 2011 respectively), however, these analyses take different approaches and the data are not directly comparable across the two languages. We conducted our own corpus analysis of the frequency and distribution of voicing alternations in Dutch and German using a corpus of child directed speech available through the CHILDES database (MacWhinney, 2000). It is likely that there will be differences between child directed and adult directed speech, therefore we do not claim that these data necessarily reflect the patterns in the languages as a whole[4], however, we are interested in the input that the child receives.

From the CLPF (Fikkert, 1994; C. C. Levelt, 1994) and Van Kampen (Van Kampen, 1994) corpora for Dutch, and the Leo and Rigol (Behrens, 2006) corpora for German we took all transcripts where the child was under 3;6[5]. This

[4] However see van de Vijver & Baer-Henney, 2011 and Chapter 4 of this thesis for similarities between CDS and ADS.

[5] Transcripts

upper age-limit corresponded to the age of the children participating in our experimental task. Following van de Vijver and Baer-Henney (2011) we extracted all singular nouns ending in an obstruent that take a vowel-initial plural suffix from the adult speaker tiers of our sub-corpus. In line with the prior discussion about the limited voicing contrast in Dutch, only the coronal and labial plosives were included for Dutch, though we refer to obstruents in both languages. Each word-final obstruent was labeled as alternating or not, i.e. underlyingly voiced or voiceless. Total type and token counts, and the proportion of alternations, are presented in Table 2.

Table 2

Child Directed Speech - Stem final obstruents in Dutch and German.

	Nouns with final obstruent (total)		*Nouns with final alternating obstruent (total)*		*Proportion nouns with alternation (%)*	
	Types	*Tokens*	*Types*	*Tokens*	*Types*	*Tokens*
Dutch	257	4410	85	2212	33%	48%
German	830	20787	298	9252	36%	45%

The German and Dutch corpora are not equally sized, but the distribution of alternations is of greater interest and therefore the proportion of noun-stems with an alternation can be taken as a more comparable figure. Regardless of whether type or token frequencies are considered, the proportion of alternating noun stems is similar in both Dutch and German: of the singular nouns with a final obstruent that a German or Dutch child hears, approximately one third of all word types will end in a neutralised obstruent. With regards to token frequency, the stem-final obstruent of a noun has an almost equal chance of being alternating as not. It should be noted that this result is different to that of Kerkhoff (2007), who found 60% of Dutch tokens to be alternating. In contrast to our data she excluded stems where the final segment was preceded by an obstruent or liquid and these are included in our data set.

CLPF corpus: all transcripts. Van Kampen corpus: laura01-laura41, sarah01-sarah34. Leo corpus: le011112-le030529. Rigol corpus: cs000013-cs030513, pa000012-pa030519, sb000017-sb030519.

Stem forms alone do not provide the child with enough evidence to establish whether the final obstruent is alternating or not. It is only in the context of the morphological paradigm that alternations become apparent. From the same corpora we also extracted the corresponding plural form of each noun stem providing us with all singular-plural pairs in the corpus where the noun stem has a final obstruent (cf. Kerkhoff, 2007).

Table 3

Singular-Plural pairs in Dutch and German child directed speech.

	Plural forms		*Plurals with alternation*		*Plurals with alternation (%)*	
	Types	*Tokens*	*Types*	*Tokens*	*Types*	*Tokens*
Dutch	57	493	22	158	38.6	32
German	196	2495	72	1572	36.7	63

Proportionally there is little difference between the number of different noun plurals that contain an alternation in Dutch and German: 38.6% of Dutch plural types are alternating and 36.7% of the German plural types. A larger difference is found in the token frequency of these forms. In Dutch, only 32% of the plural tokens are part of a morphological paradigm with a voicing alternation, whereas in German the proportion is 63%. It is debatable whether type or token frequency is of greater importance for the child to establish intraparadigmatic links. There is evidence that points to the role of type frequency (e.g. Ernestus & Baayen, 2003, 2007), but hearing multiple tokens presents the child with phonetically variable evidence, for example from different speakers of in different auditory situations, and such variability is also known to aid the formation of abstract representations (Pierrehumbert, 2003; Richtsmeier et al., 2011). If token frequency is important for acquisition of alternations, Dutch children do not receive as much evidence for alternations in nominal paradigms as German children do. Although the proportion of plural types containing alternations heard by German and Dutch children is similar, in German these items are encountered more frequently.

In sum we found that German children receive more cues in their input that they may use to aid their acquisition of voicing alternations. We predict that in age-matched samples, German children will have more robust knowledge of lexical items with voicing alternations than their Dutch-learning peers. This prediction is grounded in the patterns of the phonological system and lexical frequency of alternations in their input.

In this study we investigated children's lexical representations of voicing alternations in familiar words using an online perception study. The voicing alternation apparent in Dutch and German is an example of an interaction between a phonotactic constraint restricting voicing in the coda and morphophonological alternations.

Theories of learnability of morphophonological alternations (Albright & Hayes, 2011; Hayes, 1999; Peperkamp & Dupoux, 2002; Tesar & Prince, 2003) have predicted that phonotactics are easy to acquire and morphophonological alternations will be acquired later once the lexicon and morphological awareness have been established. Experimental data supports this, indicating that language-specific phonotactic patterns are acquired early (Friederici & Wessels, 1993; Friedrich & Friederici, 2005; Kajikawa, Fais, Mugitani, Werker, & Amano, 2006; Mattys, Jusczyk, Luce, & Morgan, 1999; Mattys & Jusczyk, 2001).

Previous research on morphological alternations in Dutch and German have investigated children's productions only (Kerkhoff, 2007; Van de Vijver & Baer-Henney, 2011; Zamuner et al., 2011). The common finding in these studies is that the production of voicing alternations in known words remains difficult until at least school age, though there is a striking difference between the performance of Dutch and German children; in accordance with our predictions, German children outperformed their age-matched Dutch peers. These studies also tested children's ability to generalise voicing alternations to unknown or novel words in wug-test style experiments (Berko, 1958). In neither language did children produce many voicing alternations when inflecting nonsense words, although German children have a tendency to do so more often than Dutch children.

This study aimed to further this literature by using a task that does not rely on children's productions. Using an online measure we hoped to investigate the difference between Dutch and German learners' performance in greater detail. We did this using the Intermodal Preferential Looking Task (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 2009), testing 3-year-olds' sensitivity to mispronunciations of voicing word-medially in familiar plural words, e.g., **betten* for *bedden* or **pedden* for *petten*. Since Swingley and Aslin (2000) this procedure has often been used to test the phonetic specificity of young children's lexicons (e.g. Bailey & Plunkett, 2002; Ballem & Plunkett, 2005; Fennell & Werker, 2003; Mani & Plunkett, 2007; Mills et al., 2004; Swingley, 2003, 2009; Van der Feest, 2007). It is assumed that if the target word is familiar, and the mental lexicon contains a detailed phonetic representation of the word, participants will notice mispronunciations in the word's form. Sensitivity is measured in their looking behaviour. When faced with two pictures, the target and a distractor, a child will look less, and less quickly, to the target picture when the label heard contains a mispronunciation compared to when it is correctly pronounced.

Previous studies have investigated mispronunciations of voicing in word-onset position. In this position mispronunciations are likely to be highly salient due to its importance for lexical access. Adults and children alike interpret speech incrementally, briefly activating all words that are consistent with the input up to that point (Fernald, Pinto, Swingley, Weinberg, & McRoberts, 1998; Fernald, Swingley, & Pinto, 2001; Huang & Snedeker, 2011; Magnuson, Dixon, Tanenhaus, & Aslin, 2007). Gradually, as the input word unfolds all other candidates drop out and only the intended word is remaining. Despite the importance of word-onset position, this paradigm has previously been used with mispronunciations occurring in word-final (Swingley, 2009) and word-medial (Bowey & Hirakis, 2006; Swingley, 2003) position. Swingley (2003) found that Dutch 19-month-olds can detect mispronunciations of place of articulation from *baby* to *bady* or *bagy*. Frauenfelder, Scholten and Content (2001) also found that adults' lexical access is disrupted by word-medial mispronunciations. Indeed, Cole and Perfetti (1980) argued that listeners might be more sensitive to mispronunciations word-medially as they have already accessed the intended word from the correct first syllable, thereby making the second syllable more predictable and the mispronunciation more prominent. This explanation is likely to be more applicable in natural speech where the context is not as restricted as an experimental paradigm in which the context is reduced to two pictures and the label is quite predictable.

We were primarily interested in children's sensitivity to mispronunciations of stem-final obstruents that occur word-medially in plural forms. This is the position where alternations occur, or may occur. We included monomorphemic, bisyllabic words as a control condition (e.g., **kedding* for *ketting* or **latter* for *ladder*). These words contained a word-medial obstruent in the same phonological context, but the absence of a morpheme boundary makes this a position where an alternation cannot occur. Therefore, in these words we expected children to detect mispronunciations.

We expected German children to have a more robust lexical representation of voicing alternations, and that they would display sensitivity to mispronunciations of voicing in both monomorphemic and plural trials. Dutch children, on the other hand, should detect mispronunciations in monomorphemic trials, but possibly not, or at least not as strongly, in plural trials. That is, we expected mispronunciations of voicing in plural words to be more disruptive to word recognition for German children than Dutch children. Experiment 1 reports the Dutch data, and Experiment 2 the German data.

Experiment 1

Method[6]

Participants.

37 Dutch-speaking children, with an average age of 37 months and 29 days (range: 37 months and 7 days to 38 months and 25 days, 19 girls), were included in the analysis. A further three children were tested but excluded from this analysis for fussiness or not participating in at least 8 of the 16 test trials. Children were recruited through the Baby Research Center of the Max Planck Institute for Psycholinguistics and Radboud University Nijmegen.

Materials.

The stimuli consisted of 16 bisyllabic nouns with word-medial /t/ or /d/. Half of the words were plural forms and half were monomorphemic (singular)

[6] Note that Experiment 1 of this chapter is the same as the post-vocalic condition reported in Experiment 2 of Chapter 4.

forms. Mispronunciations were created by changing the voicing value of the word-medial /t/ or /d/, i.e. /t/ became [d] and /d/ became [t].

Each target item was yoked with a distractor item that should be familiar to 3-year-olds. The label of the distractor item had the same onset consonant as the target in order to delay participants' ability to make a decision until later in the word.

Items were selected on the basis of the following five criteria: (1) the medial obstruent should be intervocalic; (2) items should be easily depictable; (3) items should be familiar to children of this age; (4) mispronunciations should result in non-words; (5) targets should have a higher token frequency in the singular than the plural.

Criterion 5 limits the possibility that children are not interpreting highly frequent plurals, for example *tanden* 'teeth', as morphologically complex but instead treating them as non-decomposable units (Tesar & Prince, 2003). Frequency counts were obtained from the web-based CELEX lexical database (http://web.phonetik.uni-frankfurt.de/simplex.html[7]; Baayen et al., 1993). One item, *noten* 'nuts', violates this condition in both CELEX and CHILDES counts, however, as it conformed to all other criteria and, in the absence of a more appropriate item we nevertheless included it as a target word. Another item, *botten* 'bones', violates this condition in the CELEX count only, however, there is a difference in use of the item between child and adult language. In adult language *botten* is more frequently used to refer to bones as found in a skeleton and therefore in the plural. It is this information that is captured by CELEX. In the lexicon of a child the word *bot* is more often used in the context of a dog's bone, and occurs in the singular more often than the plural. This information is captured by the CHILDES frequency count, and conforms to our inclusion criteria.

The notion of familiarity to the child was addressed initially by selecting items that were likely to be known by 3-year-olds. These were chosen from the Dutch version of the MacArthur Communicative Development Inventory (Zink & Lejaegere, 2002). This list does not provide information about inflected forms of individual lexical items[8], and we were specifically interested in this morphological complexity. We also took data from the same corpora of children's speech

[7] Thanks to Henning Reetz for making this web interface available.

[8] nCDI 3 does contain more general questions about children's use of inflectional morphology.

discussed in the corpus analysis of child directed speech above, namely the CLPF (Fikkert, 1994; C. C. Levelt, 1994) and the van Kampen (Van Kampen, 1994) corpora up to the age of 3;6 accessed through the CHILDES database (MacWhinney, 2000). We did not distinguish whether the word was uttered by the child or an adult, assuming that if an item occurs in the corpus it has been uttered in the presence of the child and may form part of their receptive lexicon, if not yet their productive lexicon.

Familiarity to each target and distractor item was measured per child, with items removed that individual children were reported not to know. One week before participating in the experiment parents were sent a picture book containing 64 colour images and their written names. All images would appear in the experiment as either a target, distractor or filler item. The purpose of the book was to establish which items were familiar to the child, therefore they were presented in the singular only. Parents were asked to read the book with their child and indicate on the accompanying questionnaire which words their child said and which words their child understood but did not produce. They were further asked whether their child recognised the image as its intended referent. We considered an item to be known by the child if the answer to any of these three questions was yes. Eye-gaze data was removed from analysis for trials where the child was unfamiliar with either the target or distractor item.

Table 4

Frequency information and canonical pronunciation of stimuli in Experiment 1.

Word Type	*Item*			*CELEX freq.*		*CHILDES freq.*		*Yoked distractor*	
				sg	pl.	sg.	pl.		
Plural /t/	botten	[bɔtən]	bones	314	590	7	0	bomen	trees
	fluiten	[flœytən]	flutes	201	30	41	22	fietsen	bikes
	noten	[notən]	nuts	379	402	5	1	neuzen	noses
	petten	[pɛtən]	caps	698	97	17	1	peren	pears
Plural /d/	bedden	[bɛdən]	beds	12052	499	258	2	boeken	books
	broden	[brodən]	breads	2616	99	79	2	brillen	glasses
	hoeden	[hudən]	hats	1314	186	174	2	handen	hands
	kleden	[kleɪdən]	rugs	455	57	2	0	klokken	clocks
Monomorphemic /t/	boter	[botər]	butter	976		8		beker	cup
	gieter	[xitər]	watering can	39		25		glijbaan	slide
	ketting	[kɛtɪŋ]	necklace	524		13		kussen	cushion
	sleutel	[sløʏtəl]	key	1481		23		spiegel	mirror
Monomorphemic /d/	ladder	[lɑdər]	ladder	506		16		lepel	spoon
	pudding	[pʏdɪŋ]	pudding	96		0		puzzel	puzzle
	ridder	[rɪdər]	knight	299		0		robot	robot
	schaduw	[sxadyw]	shadow	2233		8		schouder	shoulder

Audio stimuli were produced by a female Dutch speaker in a child-directed manner. Recordings were made in a sound-treated recording booth and digitised at a sampling rate of 44.1kHz and resolution of 16 bits in Adobe Audition. Stimuli were edited using Praat (Boersma & Weenink, 2011). The duration and average pitch of each item are given in Appendix I. There were no systematic differences in the duration ($t(15) = -.19$; $p = .86$) or pitch ($t(15) = .43$; $p = .67$) of correctly and incorrectly pronounced words. Intensity was equalised to 65dB.

Visual stimuli were photographs of objects on a grey background (r,g,b = 153), presented side by side on the 17-inch TFT monitor of a Tobii T60 eye tracker. A thin black vertical line divided the screen in two, and each photograph was positioned in the middle of the screen-half. Three adult native Dutch speakers verified that the images were typical exemplars of the labeled category as would be understood by a young child.

Procedure.

Children sat on their caregiver's lap 60 cm away from the Tobii monitor in a dimly lit room. Throughout the experiment the caregiver listened to masking music interspersed with speech through closed headphones. Stimuli were presented using Tobii-Studio software, and auditory stimuli were presented through centrally located loudspeakers below the screen. The test began with a 9-point calibration procedure. If not all points were calibrated in the first attempt, individual points were recalibrated a second time. The test began immediately after calibration.

Each child was presented with 32 trials divided into four blocks of eight trials. 16 trials were test trials and 16 were filler trials. Test trials were equally divided over correct and mispronunciation trials, counterbalanced for underlying voicing and morphological complexity. There was no repetition of the same item appearing in both a correct and mispronunciation trial. Filler trials were always correctly pronounced, and served to increase the ratio of correctly pronounced to mispronounced trials to 3:1. Filler trials were not analysed.

Table 5

Example of experimental design. One participant would be presented with correct pronunciations of items with a white background, and mispronunciations of items with a grey background. Another participant would be presented with the reverse of this pattern.

Plural [t]	*Plural [d]*	*Monomorphemic [t]*	*Monomorphemic [d]*
botten	bedden	boter	ladder
fluiten	broden	gieter	pudding
noten	hoeden	ketting	ridder
petten	kleden	sleutel	schaduw

A fixation cross was displayed in the centre of the screen for 500ms prior to each trial. After a silent preview of the images lasting 1600 ms the child heard *kijk!* ("look!"). 900ms later, or 2500ms from the trial begin, the target word was presented. The trial ended after a further 2500ms.

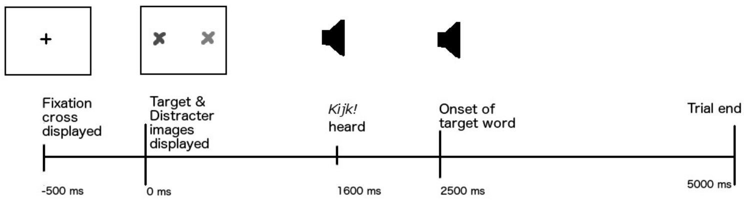

Figure 1. Time-course of a typical trial in Experiment 1

Data Analysis.

A number of pre-defined exclusion criteria were applied to the data. Firstly, unreliable measurement points were removed. The eye tracker codes each measurement point for validity or reliability from 0 (certain) to 4 (data missing or definitely incorrect). Following the recommendation of the manufacturer ("Tobii Studio 1.X User Manual," 2008), measurement points with a validity code of 2 or higher were removed. This includes points where the child was not looking at the screen and points where the tracking quality was poor.

Secondly, we removed data from whole trials if (1) if the child did not look to the screen at all during the trial; (2) if they did not look to both displayed images during the 2500 ms prenaming window; or (3) if they did not look to either the target or distractor for at least 100 ms in the 2500 ms after the target onset. This ensured that we only included trials where the child was participating in the task.

Thirdly, trials were removed on the basis of parental report. Using the data from parent's questionnaires we removed trials from the analyses in which the child was unfamiliar with either the target or yoked distractor. 136 trials were removed for this reason.

The final criterion applied was to remove the participant from further analysis if, following all exclusion criteria, there were fewer than 50% of test trials remaining (fewer than 8 out of 16 trials). Data from three children were removed. On average each child contributed 12.73 trials, out of a possible 16, to the analysis (*SD* = 2.4, range = 9-16). Appendix II shows the distribution by lexical item of items remaining in the analysis.

Two areas of interest (AOIs) were defined in the display. Each AOI corresponded to half of the display, excluding a 10 pixel-wide vertical line down the centre. Large AOIs were used to compensate for variability in children's looking behaviour or miscalibration of the eye tracker. The screen was blank apart from the experimental images, therefore there was nothing else visible for the child to fixate their gaze upon. Fixations within either of the screen halves were considered to be object fixations. Fixations falling outside either AOI were considered as off-screen and not included in the analysis. Looks to the AOIs were coded for whether they were looks to the target or distractor.

We used Growth Curve Analysis (GCA) with orthogonal polynomials to quantify differences in the time-course of gaze behaviour towards the target picture in the different test conditions. GCA is a multi-level modeling framework designed to analyse change over time at group and individual levels (Singer & Willett, 2003). The time over which change is measured is not important, and could be months or milliseconds, making this method suitable for analysing time course of fixations in an eye tracking study (see Mirman, Dixon, & Magnuson, 2008 for details of this method as applied to eye tracking data).

The time window of analysis was 1300 ms in duration. This window is comparable to a traditional analysis which takes a window of analysis from 367-1367 ms after target word onset (e.g. Van der Feest, 2007). The end of the time window of analysis corresponds to the point where children have fixated on the target, and before their attention wanes and they look away.

The time window of analysis began at the onset of the target word. Using GCA we did not have to delay the start of the analysis window to allow time for an eye movement to be made, driven by children's response to the target word, as the model can indirectly take the onset of the slope into consideration. It is in any case unclear what a suitable latency would be for 3-year-olds. Studies using the Visual World Paradigm with adults assume a latency of 200 ms (e.g. Allopenna, Magnuson, & Tanenhaus, 1998) whereas the assumed mean latency for infants is 367 ms (e.g. Swingley & Aslin, 2000). As noted by Swingley and Aslin (and references therein), minimum latencies to mobilise an eye movement in children can be as short as 233 ms, and they assume 367 ms as an "educated guess". Since the publication of Swingley and Aslin (2000) 367 ms has become the standard assumption in the field, despite, to the best of our knowledge, not having been tested further. This latency may well be a fair assumption for younger infants typically tested in many eye tracking studies, often between the ages of 18 and 24 months (e.g. Mani, Coleman, & Plunkett, 2008; Swingley & Aslin, 2000), and even as young as 12 months old (Mani & Plunkett, 2010). The children in our study were 38 months old, and, as it is well established that eye movement latency decreases with age (Miller, 1969), it is logical to assume that 3-year-olds will be faster in programming an eye movement than 18-month-olds.

GCA captures the pattern of the gaze behaviour data using two hierarchically related submodels. The first submodel, Level 1, captures the effects of time on fixation proportions using third-order orthogonal polynomials. A third-order polynomial was necessary to capture the S-shape of the data; the initial 50% fixations on the target, the following increase in fixations to the target and the final plateau. Other polynomials capture different elements of the shape of the data. By introducing orthogonal polynomials the intercept reflects the average height of the curve, making it analogous to more traditional analyses that average fixations over a specific time-window. The linear term reflects the overall angle of the curve (a straight line), and the cubic term reflects a symmetric rise and fall rate around a central inflection point.

The Level 2 submodel captures the effects of experimental manipulation on the Level 1 intercept and linear time terms. Fixed effects of Pronunciation (correct or mispronounced), Morphology (monomorphemic or plural) and Target Voicing (canonical /d/ or /t/), and the interaction of these effects were included. We did not include effects of experimental manipulation on all Level 1 time terms as the cognitive interpretation of such effects is unclear (Mirman et al., 2008).

The Level 2 submodel also includes random effects for individual participants and items. We include random effects of individual participants and items on all four time terms, allowing for variation in each individual's intercept, slope and curvature. Despite incurring a loss of statistical power, we included all terms to account for certain variation that is unknown in our data. Firstly, as discussed, we do not know how long it takes a 3-year-old to make a linguistically driven eye movement. Individual differences in the time needed to mobilise an eye movement and its speed, or gradient of the slope, are accounted for in our model by including these random factors. Variation at the level of the item is included because our data is time locked to the word onset. For each trial the timing of the critical obstruent relative to this point varies depending on the duration of the first syllable.

The analysis was run in R (R Core Team, 2012) using the lmer function from package lme4[9] (Bates, Maechler, & Bolker, 2013). The data is binomial, with the dependent variable either 0 or 1 as the participant's gaze can either be on target or not. The reference levels were correct pronunciation, plural and underlyingly voiced. Pairwise comparisons were calculated using the function glht from the package multcomp (Hothorn, Bretz, & Westfall, 2008).

Results

Results indicated that the effect of mispronunciations on word recognition was modified by voicing and morphological structure. Dutch children were most sensitive to mispronunciations if the target word was monomorphemic with an

[9] The model was defined as: *OnTarget ~ (Pronunciation*Morphology*TargetVoicing) * (ot1)+ot2+ot3+ (ot1+ot2+ot3 | Item) + (ot1+ot2+ot3 | Participant), family="binomial"*, where ot^x is orthogonal time raised to the power of 1, 2 or 3.

underlying /t/. Mispronunciations were more disruptive to recognition of monomorphemic than plural words, and to words with an underlying /t/ than /d/.

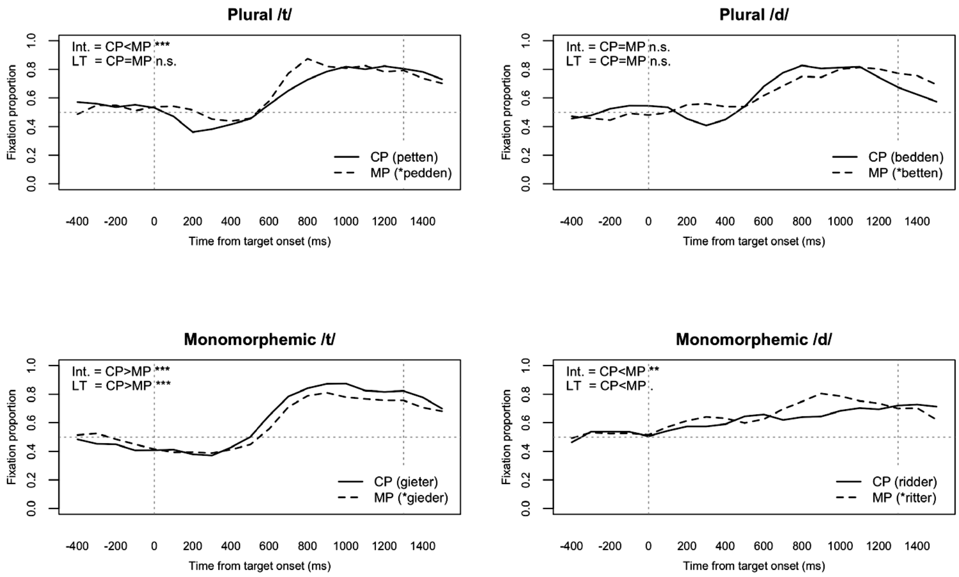

Figure 2. Target fixations to different trial types in Experiment 1. Solid lines correspond to gaze behaviour to correctly pronounced trials, and the dashed lines to mispronunciations. Looks above 50% indicate more looks to the target than distractor. The dotted horizontal line shows chance level. Dotted vertical lines indicate the window of analysis, from target onset at 0 ms for a period of 1300 ms. Int. and LT indicate statistical differences between the two lines during the analysis window, corresponding to the pair-wise comparisons displayed in Table 7.

Full results are presented in Table 6. Table 7 displays pairwise comparisons, indicating the difference in looking behaviour to correctly and mispronounced trials of each word type tested.

There was a significant effect of Pronunciation on the intercept term ($\beta = 0.23$; $SE = 0.06$; $p < .001$), indicating that overall target fixation proportions were lower for correct pronunciations of plural words with /t/ relative to mispronunciations. There were no significant effects of Morphology ($\beta = 0.04$; $SE = 0.19$; $p = .82$) or Voicing ($\beta = -0.07$; $SE = 0.19$; $p = .72$) on the intercept term.

There were no significant effects of Pronunciation, Morphology or Voicing on the linear time term.

There was a significant interaction of Pronunciation * Voicing on the intercept term, indicating a greater effect of mispronunciations on plural words with /t/ than /d/ (β = -0.26; *SE* = 0.08; $p < .001$). There was no significant interaction of Pronunciation * Voicing on the linear time term; for plural words with /t/ or /d/ there was no difference in the gradient of the slope to correct pronunciations relative to mispronunciations.

There interaction of Pronunciation * Morphology was significant on both the intercept and linear time terms (Intercept: β = -0.54; *SE* = 0.08; $p < .001$. Linear Time: β = -7.29; *SE* = 2.84; $p = .01$). Overall target fixation proportions were higher, and the gradient steeper, for correct pronunciations of monomorphemic /t/ targets relative to mispronunciations.

The interaction of Pronunciation * Morphology * Voice was also significant on both the intercept and linear time terms (Intercept: β = 0.76; *SE* = 0.11; $p < .001$. Linear Time: β = 16.48, *SE* = 3.99, $p < .001$). Indicating that the difference in the size of the mispronunciation effect for monomorphemic words with /t/ or /d/ is larger than the difference in the size of the mispronunciation effect between plurals with /t/ or /d/, and this is reflected in both the height and gradient of the curve.

Multiple comparisons (Table 7) indicated an effect of Pronunciation, that is, a significant difference in looking behaviour to correct and mispronunciations, of plural /t/ targets on the intercept term, monomorphemic /t/ targets on both the intercept and linear time terms, and monomorphemic /d/ targets on the intercept term. In summary, participants displayed some sensitivity to mispronunciations in all trial types, with the exception of plural /d/ words. The degree of sensitivity to mispronunciations was attenuated by both underlying voicing and morphological structure.

Table 6

Growth Curve Analysis of target fixation proportions, Experiment 1.

Effect	*Estimate*	*SE*	*z-value*	*p-value*
Intercept	0.87	0.21	4.17	< .001 ***
Pronunciation (CP vs. MP)	0.23	0.06	4.14	< .001 ***
Morphology (plural vs. monomorphemic)	0.04	0.19	0.23	.82
Voicing (/t/ vs. /d/)	-0.07	0.19	-0.35	.72
Linear Time	24.69	6.26	3.95	< .001 ***
Quadratic Time	3.39	2.62	1.29	.2
Cubic Time	-9.47	2.22	-4.27	< .001 ***
Pronunciation * Morphology	-0.54	0.08	-7.1	< .001 ***
Pronunciation * Voicing	-0.26	0.08	-3.49	< .001 ***
Morphology * Voicing	-0.92	0.27	-3.38	< .001 ***
Pronunciation * Linear Time	-1.23	2.07	-0.59	.55
Morphology * Linear Time	5.52	5.29	1.04	.3
Voicing * Linear Time	3.96	2.28	0.75	.45
Pronunciation * Morphology * Voicing	0.76	0.11	6.99	< .001 ***
Pronunciation * Morphology * Linear Time	-7.29	2.84	-2.57	.01 *
Pronunciation * Voicing * Linear Time	-2.79	2.79	-1	.32
Morphology * Voicing * Linear Time	-1.95	7.52	0.26	.8
Pronunciation * Morphology * Voicing * LT	16.48	3.99	4.13	< .001 ***

Note. ***p < .001. **p < .01. *p < .05. . p < .1

Table 7

Comparison of the effect of Pronunciation on different trial types in Experiment 1.

Word type		*CP Est.*	*MP Est.*	*Difference between CP and MP*	*SE*	*z-value*	*p-value*
Plural /t/	Int.	0.87	1.1	0.23	0.05	4.14	< .001 ***
	L.T.	24.69	23.46	-1.23	2.07	-0.59	.99
Plural /d/	Int.	0.81	0.77	-0.03	.05	-0.64	.99
	L.T.	28.64	24.62	-4.02	1.87	-2.15	.17
Mono. /t/	Int.	0.92	0.6	-0.31	0.05	-5.98	< .001 ***
	L.T.	30.21	21.69	-8.51	1.93	-4.42	< .001 ***
Mono. /d/	Int.	-0.07	0.11	0.18	0.06	3.18	.008 **
	L.T.	32.21	37.89	5.17	2.06	2.51	.07 .

Note. Corrected p-values for all contrasts, including plural /t/.

Discussion

Results indicated that Dutch 3-year-olds are sensitive to mispronunciations of voicing in word-medial position. In three of the four words types tested their gaze behaviour to correct and mispronunciations differed; monomorphemic words with either /t/ or /d/, and plurals with /t/. They were not sensitive to mispronunciations of /d/ in plural word forms. Interaction terms indicated that mispronunciations of plural /t/ are significantly more noticeable than plural /d/, and mispronunciations of monomorphemic words with /t/ were more disruptive to word recognition than mispronunciations of plural words with /t/. To summarise, in line with our predictions we found that Dutch children are sensitive to mispronunciations of voicing word-medially in monomorphemic words. In plural words they show asymmetric sensitivity regarding the direction of the mispronunciation; they notice mispronunciations of voiceless to voiced, but not vice versa. In addition, although children were sensitive to mispronunciations of voicing in monomorphemic /d/ words, this effect was small.

Morphological structure plays a role in Dutch children's representations of voicing. The difference between sensitivity to mispronunciations of voicing in plural words is in line with a dual-route theory of lexical representation of morphologically complex words (Baayen et al., 1997, 2003), where the lack of overlap between stem and inflected form with an alternation encourages full-form access. The mental lexicon contains "regular" plurals formed through the suffixation of *-en* to the stem, i.e. *pet* and *petten*. For less transparent paradigms the child's lexicon contains two representations; one is the regular formation e.g. *betten,* and the other is the "irregular" form *bedden* heard in the input. Both forms equally facilitate lexical access. The child never encounters overregularisations of regular forms, e.g. *pedden*, and these forms are therefore not represented in the mental lexicon and are disruptive to lexical access.

Asymmetric sensitivity to mispronunciations of voicing could be explained in terms of phonological representations, in line with previous data from Van der Feest (2007). In her study she found that Dutch 2-year-olds were sensitive to mispronunciations of voiceless obstruents in word-initial position, but not to mispronunciations of voiced obstruents. She argued for underspecification of the feature [voice], assuming that voiced obstruents are specified for the feature [voice] and voiceless obstruents are underspecified. Production data from Dutch children support this analysis, with devoicing errors, that is, defaulting to the unmarked value, being more common than voicing errors (Kager, Van der Feest, Fikkert, Kerkhoff, & Zamuner, 2007). A similar asymmetry could be accounted for by acoustic salience. In Dutch, the predominant cue for voicing is the presence or absence of vocal fold vibration through the closure phase of the plosive (cf. Van Alphen & Smits, 2004). The presence of voicing is interpreted unequivocally as voiced whereas the absence of the cue is interpreted as either voiced or voiceless. Van Alphen and Smits (2004) provide evidence for this perceptual asymmetry in word initial position in Dutch adults using stimuli where the voicing has been removed. However, the asymmetry does not extend to lexical access using natural stimuli (Van Alphen & McQueen, 2006). From the Dutch data alone it is not possible to distinguish between these two accounts. Our data do not show that children were not sensitive to mispronunciations of voiced to voiceless at all, but that these mispronunciations were less disruptive to word recognition than mispronunciations in the opposite direction.

The acoustic correlates of the voicing contrast differ between Dutch and German. Whereas Dutch is a voicing language, German is an aspirating language. This has been argued to be relevant for laryngeal feature representations of the voicing contrast in each language. Dutch represents voicing with the feature [voice]; /d/ is specified for [voice] and /t/ is unspecified. The relevant feature in German is [spread glottis], where /t/ is specified for [spread glottis] and /d/ is unspecified (Jessen & Ringen, 2002; Jessen, 1998; Kager et al., 2007). Kager et al. (2007) argued that children's productions in each of the languages support this interpretation. As mentioned, Dutch children make more devoicing errors, however German children are shown to make more voicing errors. Data from Experiment 1 do not contradict this theory, and provide a prediction for Experiment 2. If German children have an underspecified representation of the feature [spread glottis] then they will be sensitive to mispronunciations of /d/ to [t], but not the reverse. This is the opposite pattern as attested in Experiment 1.

An unexpected result in Experiment 1 was the poor recognition of monomorphemic words with /d/. Despite being sensitive to mispronunciations of monomorphemic words with /d/ it is striking is how weakly correct pronunciations of these words were recognised. Fixations to correctly pronounced monomorphemic /d/ words were barely above chance level, thus making the asymmetry of voicing difficult to interpret reliably. The question raised is why were these words not recognised as well as the other words, particularly because we controlled for familiarity of items using parental report. Table 8 indicates the number of children unfamiliar with each target item used in Experiment 1. What is apparent from this data is that plural words with /d/ and monomorphemic words with /t/ are similarly familiar to children, and monomorphemic words with /d/ and plurals with /t/ are much less well known. However, plural words with /t/ were recognised better in the task.

As a further check of familiarity, we looked at the by-item estimates of our model output. There is no one item that stands out as not being recognised, however the class of monomorphemic /d/ words behave differently to all other categories. It seems, therefore, that removing items on the basis of parental report was justified in plural /t/ trials and the trials remaining in the analysis did come from children who were familiar with these items and recognised them in the task. It does not explain why children were poor to recognise monomorphemic /d/ trials.

A final possibility is that the monomorphemic /d/ words are less easily depictable than other conditions and therefore less recognisable by the participants. According to the parental reports a number of children knew the words *schaduw* and *pudding* but did not associate the presented image with these word forms. Because the word form was indicated as being known by the children we included these trials in the analysis, but maybe the images were not clear. It is difficult to remove these trials reliably from the analysis as there are inconsistencies in how parents completed the questionnaire.

Table 8

Number of children for whom each item was unfamiliar, based on parental report.

Plural	*Unfamiliar*	*Monomorphemic*	*Unfamiliar*
botten	12	boter	6
fluiten	6	gieter	2
noten	12	ketting	3
petten	7	sleutel	1
bedden	1	ladder	3
broden	2	pudding	10
hoeden	2	ridder	13
kleden	7	schaduw	12

The aim of this study was to compare Dutch-learning children's representations of voicing alternations with age-matched German-learning peers. On the basis of differences in the phonological systems of the two languages and lexical frequencies, teamed with results from previous production studies, we predicted that Dutch children will have less robust representations of voicing alternations compared to their German-learning peers. Experiment 2 replicates Experiment 1 with German-learning children. We predicted that German children will have a more robust representation of voicing and will display sensitivity to mispronunciations of both monomorphemic and plural words. In addition, on the basis of the result from Experiment 1, we have a hypothesis relating to potential asymmetries in the direction of sensitivity to voicing mispronunciations in German.

Experiment 2

Method

Participants.

23 German-speaking children with an average age of 37 months and 22 days (range: 36 months and 1 day to 39 months and 1 day, 12 girls) participated in

this experiment. One further child was excluded from the analysis for fussiness. Children were recruited through the BabyLab of the University of Potsdam.

Materials.

Materials were selected according to the same criteria as Experiment 1. It was not possible to find 16 target nouns with the target obstruent appearing in intervocalic position. We included 5 words wherein the target obstruent appeared after a sonorant (either [r], [l] or [n]). Note, however, that /r/ is vocalised following a long vowel in German. We did not expect these different contexts to have an influence on results. In addition, two target items did not fulfill the criterion that the mispronunciation should result in a non-word; the mispronunciations of *Leiter* and *Feder* are, for some speakers, the same as the real words *leider* 'unfortunately' and *Väter* 'fathers'.

Table 9

Frequency information and canonical pronunciation of Experiment 2 stimuli.

Word Type	*Item*			*CELEX Freq.*		*CHILDES Freq.*		*Yoked distractor*	*Gloss*
				sg.	*pl.*	*sg.*	*pl.*		
Plural /t/	Betten	[bɛtən]	beds	476	218	782	40	Bretter	boards
	Brote	[broːtə]	breads	166	5	410	30	Boote	boats
	Schwerter	[ʃveːɐtɐ]	swords	44	15	27	0	Schwänze	tails
	Zelte	[tsɛltə]	tents	33	17	30	0	Zehe	toes
Plural /d/	Hunde	[hʊndə]	dogs	207	118	399	68	Hände	hands
	Kleider	[klaidɐ]	dresses	90	111	31	38	Klaviere	pianos
	Monde	[moːndə]	moons	354	53	443	18	Münde	mouths
	Pferde	[pfeːɐdə]	horses	170	152	269	87	Pflaster	plasters
Monomorphemic /t/	Beuten	[bɔytəl]	bag	11		26		Becher	beaker
	Garten	[gartən]	garden	237		169		Gabel	fork
	Leiter	[laitɐ]	ladder	335		161		Lampe	lamp
	Schulter	[ʃʊltɐ]	shoulder	207		31		Schlüssel	key
Monomorphemic /d/	Erde	[eːɐdə]	earth	1071		154		Erdbeer	strawberry
	Feder	[feːdɐ]	feather	65		5		Fenster	window
	Nadel	[naːdəl]	needle	17		5		Nase	nose
	Weide	[vaidə]	meadow	15		28		Wolke	cloud

Speech stimuli were recorded by a female speaker of German in a child friendly manner in a sound-treated recording booth. Stimuli were recorded and prepared using the same equipment and in the same manner as Experiment 1. Acoustic information is presented in Appendix III. There were no systematic differences in the duration ($t(15) = .32$; $p = .75$) or pitch ($t(15) = .55$; $p = .59$) of the correctly and incorrectly pronounced words. Intensity was equalised to 65dB.

Visual stimuli also conformed to the same criteria as applied in Experiment 1. Three adult native German speakers verified that all images were typical exemplars of the labeled category as would be understood by a young child.

Procedure.

The task was identical to Experiment 1, with a few minor alterations due to the different lab. Children sat independently on a chair or on their caregivers lap, with their face 60-70 cm away from the Tobii monitor in a dimly lit room. If the child was on their caregivers' lap, the caregiver wore blacked-out glasses so they could not see the images displayed on the screen. If the child sat alone, the parent sat on a chair located behind the child. Stimuli were presented using ClearView software on a Tobii 1750 eye-tracker. Auditory stimuli were presented through speakers located centrally beneath the screen.

The procedure began with a five-point calibration procedure, with second calibration of individual points that were not calibrated the first time. The test began immediately after the calibration procedure.

Each child was presented with 32 trials divided into four blocks of eight trials. Half of the trials were test trials, and half filler trials. The time-course of a trial was identical to Experiment 1. A trial lasted 5000 ms, and target and distractor images were displayed for the duration of the trial. The target word was presented after 2500 ms. Before the target was labeled, the child heard *Schau mal!* ('look').

Data Analysis.

Data were prepared and analysed in the same manner as Experiment 1. Following the application of all exclusion criteria data remained for analysis from 23 participants, who contributed an average of 13.5 trials, out of a possible 16 (*SD* = 1.85, range = 11-16). This data is broken down by lexical item in Appendix IV.

Due to differences in the length of the target word, and therefore the point of the crucial obstruent, the time window of analysis was shifted by 100 ms compared to the window of analysis used in Experiment 1. The mean word length of the Dutch target items was 560 ms (*SD* = 95), and the obstruent occurred on average 266 ms after word onset (*SD* = 90). The mean word length of the German target items was 738 ms (*SD* = 87), and the mean burst of the crucial obstruent occurred 369 ms later (*SD* = 92). The increased word length delayed the peak of children's word recognition when compared to the Dutch data. This is visible in Figure 3 which shows the average recognition curve over all trials, regardless of pronunciation, for Experiment 1 (Dutch) and Experiment 2 (German). There are a number of differences between the curves, but most striking is the speed of target recognition. A window of 1300 ms post-onset, as used for the Dutch data, cuts off valuable information in the German data. The pattern of results for Experiment 2 does not alter significantly if this compensation is not applied to the data of Experiment 2.

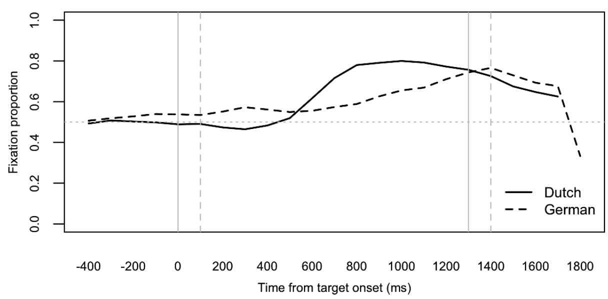

Figure 3. Average target fixation proportions for all trials in Experiment 1 (Dutch) and Experiment 2 (German). The solid vertical lines indicate the time window of analysis for Dutch data. The dashed vertical lines indicate the time window of analysis taken for the German data.

Results

Results from Experiment 2 indicated that sensitivity to mispronunciations was predominantly attenuated by Morphology. Mispronunciations had a negative impact on participants' recognition of plural words, and this did not differ depending on underlying voicing. Full results are presented in Tables 10 and 11.

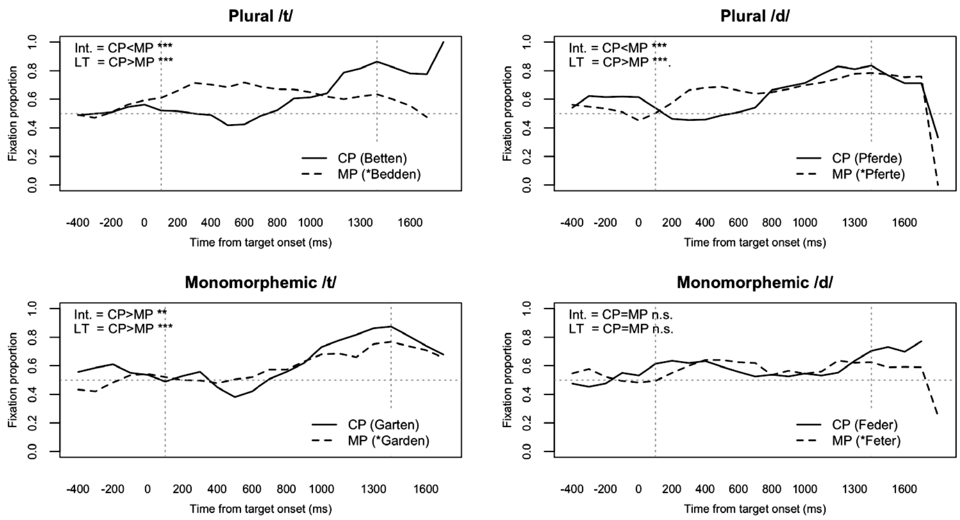

Figure 4. Target fixations to different trial types in Experiment 2. Solid lines correspond to gaze behaviour to correctly pronounced trials, and the dashed lines to mispronunciations. Looks above 50% indicate more looks to the target than distractor. The dotted horizontal line shows chance level. Dotted vertical lines indicate the window of analysis, from 100 ms after the onset of the target word for a period of 1300 ms. Int. and LT indicate statistical differences between the two lines during the analysis window, corresponding to the pair-wise comparisons displayed in Table 11.

There was a significant effect of Pronunciation on the intercept ($\beta = 0.4$; $SE = 0.07$; $p < .001$) and linear time terms ($\beta = -19.78$; $SE = 2.24$; $p < .001$), indicating that although overall target fixation proportions for correct pronunciations of plural words with /t/ were lower than mispronunciations, the gradient was steeper. There were no significant effects of Morphology or Voicing on the intercept or linear time terms.

There was a significant interaction of Pronunciation * Voicing on the linear time term ($\beta = 8.85$; $SE = 3.54$; $p = .01$), but not on the intercept term ($\beta = 0.08$; $SE = 0.1$; $p = .94$), indicating that although there was no difference in the effect of mispronunciations on overall target fixation proportions for plural words with an underlying /t/ or /d/, there is a difference in the time-course of looking behaviour. Correct pronunciations elicited a steeper response than mispronunciations. The difference in speed of recognition between correct pronunciations and mispronunciations was greater for plural /t/ targets than plural /d/ targets. Although participants were sensitive to mispronunciations of both plural /t/ and /d/ targets, the effect of mispronunciations on speed to shift gaze to target was greater for /t/ targets than /d/.

There was a significant interaction of Pronunciation * Morphology on both the intercept ($\beta = -0.63$; $SE = 0.1$; $p = < .001$) and linear time terms ($\beta = 8.41$; $SE = 3.52$; $p = .02$) , indicating that the effect of Pronunciation was greater for plural /t/ targets than monomorphemic /t/ targets. In addition, the significant interaction Pronunciation * Morphology * Voicing ($\beta = 0.35$; $SE = 0.14$; $p = .01$) indicated that the difference between the effect of Pronunciation on overall fixation proportions was less pronounced for plural /t/ and /d/ words than monomorphemic /t/ and /d/ words.

Pairwise results (Table 11) indicated a significant effect of Pronunciation, on the intercept and linear time terms of all trial types with the exception of monomorphemic /d/ trials.

Table 10

Growth Curve Analysis of target fixation proportions, Experiment 2.

Effect	*Estimate*	*SE*	*z-value*	*p-value*
Intercept	0.29	0.24	1.22	0.22
Pronunciation (CP vs. MP)	0.4	0.07	5.99	< .001 ***
Morphology (plural vs. monomorphemic)	0.33	0.23	1.44	.15
Voicing (/t/ vs. /d/)	0.07	0.23	0.33	.74
Linear Time	17.71	6.63	2.67	.007 **
Quadratic Time	4.46	3.41	1.31	.19
Cubic Time	0.37	2.48	0.15	.88
Pronunciation * Morphology	-0.63	0.1	-6.58	< .001 ***
Pronunciation * Voicing	0.008	0.1	0.08	.94
Morphology * Voicing	-0.23	0.33	-0.71	.48
Pronunciation * Linear Time	-19.78	2.44	-8.1	< .001 ***
Morphology * Linear Time	0.33	6.82	0.05	.96
Voicing * Linear Time	5.76	6.8	0.85	.4
Pronunciation * Morphology * Voicing	0.35	0.14	2.53	.01 *
Pronunciation * Morphology * Linear Time	8.41	3.52	2.39	.02 *
Pronunciation * Voicing * Linear Time	8.85	3.54	2.5	.01 *
Morphology * Voicing * Linear Time	-13.57	9.66	-1.41	.16
Pronunciation * Morphology * Voicing * Linear Time	6.31	5.01	1.26	.21

Note. ***$p < .001$. **$p < .01$. *$p < .05$. . $p < .1$

Table 11

Comparison of the effect of Pronunciation on different trial types in Experiment 2.

Word type		*CP Est.*	*MP Est.*	*Difference between CP and MP*	*SE*	*z-value*	*p-value*
Plural /t/	Int.	0.29	0.69	0.4	0.07	5.99	< .001 ***
	L.T.	17.71	-2.06	-19.78	2.44	-8.1	< .001 ***
Plural /d/	Int.	0.36	0.77	0.4	0.07	5.76	< .001 ***
	L.T.	23.48	12.56	-10.92	2.56	-4.27	< .001 ***
Mono. /t/	Int.	0.62	0.39	-0.23	0.07	-3.38	.005 **
	L.T.	18.05	6.68	-11.37	2.55	-4.47	< .001 ***
Mono. /d/	Int.	0.46	0.59	0.12	0.07	7.8	.36
	L.T.	10.24	14.04	3.8	2.47	1.54	.54

Note. Corrected p-values for all contrasts, including plural /t/.

Discussion

Results indicated a clear differentiation in sensitivity to mispronunciations by morphology, with mispronunciations of plural words being more noticeable than mispronunciations of monomorphemic words. As predicted, German 3-year-olds have a robust representation of voicing in plural forms and know whether a morphological paradigm contains a voicing alternation or not. We expected German children to be sensitive to mispronunciations in monomorphemic forms. Counter to our hypothesis, they did not notice mispronunciations of monomorphemic words with /d/. However, as was the case in the Dutch data of Experiment 1, this may be attributed to poor recognition of these words, even when correctly pronounced.

Some target items were included in Experiment 2 where the word-medial obstruent followed a sonorant. Although we did not expect phonological context to play a role in children's behaviour, informal analysis suggests that mispronunciations were more noticeable, or disruptive, in the post-sonorant context. A CELEX frequency count revealed that voicing alternations are more frequent in a post-sonorant context than post-vocalic. Of nouns with a stem-final /d/, in 3,057 tokens the preceding segment is a vowel, and 27,626 tokens a sonorant. Of nouns with a stem-final /t/ the frequency pattern is more balanced; 19,437 are preceded by a vowel and 18,076 by a sonorant. Therefore a stem-final obstruent preceded by a sonorant is more likely to alternate than not. Informally at least, it seems that participants in Experiment 2 were sensitive to this distribution. The role of phonological context on children's knowledge of voicing alternations is elaborated on in Chapter 4.

The final hypothesis concerned the possibility of an asymmetric sensitivity to voicing alternations. In Experiment 1 children were more sensitive to mispronunciations of /t/ than /d/, which has previously been used as evidence for underspecification of the feature [voice] (Kager et al., 2007; Van der Feest, 2007). It has also been argued that voicing in German should be represented by the feature [spread glottis], predicting the reverse asymmetry in German as was found in Dutch. This is not the case. For plural words sensitivity to mispronunciations was equal for both /t/ and /d/. Of monomorphemic words there was an asymmetry, children were sensitive to mispronunciations of /t/ but not /d/. Even if we discount monomorphemic /d/ words due to their poor recognition, the fact that children were sensitive to mispronunciations of /t/ is evidence that any asymmetry does not go in the opposite direction to Dutch. We find no evidence in our data to support the multiple feature hypothesis in children's lexical representations of voicing, despite production data to the contrary (Kager et al., 2007).

General Discussion

This paper set out to investigate Dutch and German children's lexical representations of voicing alternations using a mispronunciation detection paradigm. Previous literature has shown that voicing alternations are difficult to acquire, and 3-year-olds make many errors in their productions (Kerkhoff, 2007; Van de Vijver & Baer-Henney, 2011; Zamuner et al., 2011). We predicted that a more sensitive method than production data would indicate that their knowledge is advanced of their production ability. We further predicted that German children would outperform their Dutch peers because the phonological system and lexical distribution of voicing and voicing alternations provides them with more robust cues.

Both of our predictions were upheld in Experiments 1 and 2. Dutch- and German-learning 3-year-olds' lexical representations contain information about the voicing status of a stem-final obstruent and whether there is a voicing alternation in the morphological paradigm or not. Furthermore, German children's lexical representations are more robust than those of the Dutch children. This result provides evidence that this non-allophonic alternation is acquired earlier than previously believed (cf. Pierrehumbert, 2003). We have further demonstrated that it is not (only) the cognitive complexity of morphophonological alternations that makes them difficult to acquire, but the properties of the native language have a strong influence.

Table 12
Overview of results of Experiments 1 and 2.

	Dutch (Exp. 1)		*German (Exp. 2)*	
	Intercept (height)	*Linear Time (gradient)*	*Intercept (height)*	*Linear Time (gradient)*
Plural /t/	CP < MP ***	CP = MP n.s.	CP < MP ***	CP > MP ***
Plural /d/	CP = MP n.s.	CP = MP n.s.	CP < MP ***	CP > MP ***
Monomorphemic /t/	CP > MP ***	CP > MP ***	CP > MP **	CP > MP ***
Monomorphemic /d/	CP < MP **	CP < MP .	CP = MP n.s.	CP = MP n.s.

Note. CP = correct pronunciation, MP = mispronunciation
Note. ***$p < .001$. **$p < .01$. *$p < .05$. . $p < .1$

By conducting a cross-linguistic study we were able to separate cognitive or developmental factors from language-specific factors. Our results highlight the role of the native language and how the frequency or saliency of supposedly "difficult" structures can influence acquisition. Previous literature has hinted at the role of frequency and native language as factors in the acquisition of morphophonological alternations. For example, Fikkert and Freitas (2006) argued that variation in the input allows children to acquire alternations in the European Portuguese vowel system at an early age, and Bals (2004) reported evidence for the acquisition of phonological and morphological relationships in North Saami by the age of 2;5. However, these studies compared the age-of-acquisition of different morphophonological alternations across different languages. By comparing the acquisition of the same morphophonological alternation by children learning two typologically related languages in similar cultural environments the role of language-specific factors are highlighted, allowing us to more confidently conclude that native language properties impact on children's acquisition of morphophonological alternations.

In itself this conclusion is not spectacular. It is by now well reported that infants and children are sensitive to properties of their native language. The prevalent view is that infants are born as "universal listeners" and during the first year of life their universal abilities diminish and language specific abilities are emphasised (see Cutler, 2012, Chapter 8 for overview). Infants' sensitivity to their native language develops through a variety of statistical mechanisms that allow the infant to learn from the speech stream alone, in the absence of top-down knowledge such as a lexicon. For example, infants are able to track, and make use of, the frequency of occurrence of segments (Saffran, Aslin, & Newport, 1996), how often they co-occur (Mattys & Jusczyk, 2001), or what the predominant stress patterns is (Jusczyk, Houston, & Newsome, 1999). Previous theories of the acquisition of non-allophonic morphophonological alternations have claimed that the system cannot be acquired without top-down knowledge from morphology and semantics (Peperkamp & Dupoux, 2002; Tesar & Prince, 2003). These theories claim that phonotactic knowledge can help infants initially in identifying that voicing is not contrastive in final position, but knowledge of which morphological paradigms contain an alternation can only be derived through the addition of morphological and semantic knowledge. The difference between this theory and our results is that we show that bottom-up knowledge can help learners in learning morphophonological alternations to a greater extent than previously believed. German children performed better than their Dutch peers, and we have little reason to believe that there are substantial differences in the general linguistic or cognitive capabilities of the two groups. The difference specifically relates to how advanced their knowledge of voicing alternations is, and a number of language-specific cues were identified that may support German children's development. The cues identified were that the voicing contrast has a higher functional load in German, voicing and alternations are occur across the whole class of obstruents, and there are more lexical items with alternations. These cues can be condensed down to properties of variability and frequency, two cues which are known to be relevant for learning. We cannot tease apart the relative importance of these cues, or the contribution of other cross-linguistic differences. For example, there are many more plural allomorphs in German than Dutch, which again introduces more variability that children may be making use of.

Differences between Dutch and German children's sensitivity to mispronunciations in plural forms is relevant for theories of acquisition and the mental lexicon. We assume that the acquisition process progresses in a similar manner for both groups of learners, and that German children are further along in their development. German 3-year-olds know which morphological paradigms contain a voicing alternation and which do not, and mispronunciations are disruptive to lexical access. Dutch 3-year-olds are confident about which lexical items do not contain an alternation, and notice if voicing is erroneously added (e.g. *petten-*pedden*). On the other hand, if a paradigm should contain an alternation they are less certain about this, and both correct and mispronunciations facilitate lexical access equally. We argued in Experiment 1 that this pattern speaks in favour of a model of the mental lexicon including parallel activation of both regular and irregular forms (e.g. Baayen et al., 1997, 2003; Clahsen, 1999). Assuming that forms with a voicing alternation are more likely to be represented as a whole form, at this stage of development Dutch children have lexical representations of both the form heard in their surroundings as well as the ability to generate plurals according to the regular pattern of suffixation. Parsing complex words into constituent morphemes is supposedly slower than whole-form access according to these theories. This would predict that Dutch participants should be faster to locate the target of /d/ plural words when correctly pronounced than mispronounced. This prediction is not borne out in the data, but it may be that our method was not sensitive enough to pick up on this difference.

German toddlers are a stage further in their acquisition and no longer accept incorrectly regularly inflected forms, that is, they do not accept **Hunte* for *Hunde* where Dutch children would do so. That this does not speak against a dual-route model, but their representation of irregular forms is robust enough to reject the alternative in this experimental paradigm. We predict that a more sensitive measure would elicit differences.

We expected sensitivity to mispronunciations to be exhibited by fewer looks and / or slower shift of gaze to the target when mispronounced compared to when correctly pronounced (cf. Swingley & Aslin, 2000). This was the case for monomorphemic words with /t/ in both experiments. However, for plural trials, where they elicited a mispronunciation effect at all, children spent more time looking to the target when mispronounced than correctly pronounced. This could be interpreted as a surprise effect; children expected to hear one form, and when they encountered something else their confusion caused them to spend longer looking at what they thought the target was going to be. This interpretation does not account for the difference between monomorphemic and plural words. Why were participants surprised by a mispronunciation of a plural form, but rejected a mispronunciation of a monomorphemic form outright? An explanation can be found in their degree of certainty, and the amount of attention they pay to different word types. Voicing never alternates in monomorphemic forms and children have no reason to question the specificity of their lexical representation, and it is not interesting or challenging to them. Plural trials are more taxing, and despite our data showing that children's representations (especially German children's) are largely correct, they are more doubtful. We take this as evidence that they are in the process of learning about voicing alternations in plural forms, and predict that the surprise effect will decrease with age.

In Experiment 1 we discussed whether the asymmetry in sensitivity to mispronunciations could be attributed to underspecification of the feature [voice]. Participants noticed if the feature was added, but not if it was removed. The multiple feature hypothesis argues that because the phonetic correlates of the voicing contrast differ between Dutch and German, the more appropriate feature to represent the contrast in German is [spread glottis] and not [voice] (see Kager et al., 2007 for a discussion relating to acquisition). If this were the case, it would be predicted that sensitivity to mispronunciations of voicing in German would also be asymmetric, but the asymmetry would go in the opposite direction to Dutch. We do not find evidence to support this prediction. In Experiment 2, as in Experiment 1, mispronunciations of /t/ were more noticeable than mispronunciations of /d/.

In conclusion, we found that German children have increased knowledge of voicing alternations when compared to age-matched Dutch children. We have argued that this advantage comes from differences in the phonological system of the two languages and lexical frequency of voicing alternations. Our data speak in favour of a dual-route of lexical processing, but do not support the multiple-feature hypothesis of laryngeal specification of the voicing contrast.

Appendix I

Acoustic information of stimuli used in Experiment 1 (Dutch).

Item		*Correct pronunciations*		*Mispronunciations*	
		Dur. (ms)	*Pitch (Hz)*	*Dur. (ms)*	*Pitch (Hz)*
botten	bones	488	212	451	200
fluiten	flutes	688	214	637	206
noten	nuts	612	218	639	211
petten	caps	452	197	430	202
bedden	beds	447	201	478	209
broden	breads	613	202	665	206
hoeden	hats	434	197	440	207
kleden	rugs	606	205	674	185
boter	butter	562	172	556	197
gieter	watering can	674	207	562	205
ketting	necklace	510	197	459	197
sleutel	key	692	210	663	188
ladder	ladder	550	220	498	217
pudding	pudding	482	200	469	203
ridder	knight	476	211	631	215
schaduw	shadow	650	192	731	189

Appendix II

Number of trials remaining in analysis of Experiment 1 by item.
The maximum number of remaining trials is 37, the number of participants in the experiment.

Word type	*Target*	*Yoked distractor*	*No. of trials remaining*
Plural /t/	botten	bomen	26
	fluiten	fietsen	28
	noten	neuzen	24
	petten	peren	29
Plural /d/	bedden	boeken	33
	broden	brillen	33
	hoeden	handen	37
	kleden	klokken	28
Monomorphemic /t/	boter	beker	31
	gieter	glijbaan	31
	ketting	kussen	33
	sleutel	speigel	36
Monomorphemic /d/	ladder	lepel	32
	pudding	puzzel	27
	ridder	robot	17
	schaduw	schouder	26

Appendix III

Acoustic information of stimuli used in Experiment 2 (German).

Item		*Correct pronunciations*		*Mispronunciations*	
		Dur. (ms)	*Pitch (Hz)*	*Dur. (ms)*	*Pitch (Hz)*
Betten	beds	717	199	657	196
Brote	breads	678	198	624	193
Schwerter	swords	896	188	925	192
Zelte	tents	785	200	773	199
Hunde	dogs	582	190	620	192
Kleider	dresses	861	197	831	200
Monde	moons	898	198	772	197
Pferde	horses	685	195	730	181
Beutel	bag	695	191	698	188
Garten	garden	758	189	815	191
Leiter	ladder	751	191	823	197
Schulter	shoulder	730	188	717	181
Erde	earth	604	193	650	192
Feder	feather	780	182	768	196
Nadel	needle	670	206	704	204
Weide	meadow	746	199	657	191

Appendix IV

Number of trials remaining in analysis of Experiment 2 by item.
The maximum number of remaining trials is 23, the number of participants in the experiment.

Word type	*Item*	*Yoked distractor*	*No. of trials remaining*
Plural /t/	Betten	Bretter	20
	Brote	Boote	23
	Schwerter	Schwänze	17
	Zelte	Zehe	16
Plural /d/	Hunde	Hände	21
	Kleider	Klaviere	16
	Monde	Münde	20
	Pferde	Pflaster	21
Monomorphemic /t/	Beutel	Becher	21
	Garten	Gabel	21
	Leiter	Lampe	23
	Schulter	Schlüssel	22
Monomorphemic /d/	Erde	Erdbeer	19
	Feder	Fenster	21
	Nadel	Nase	20
	Weide	Wolke	11

4

Using phonotactic probabilities to predict voicing alternations in production and perception[1]

Introduction

It is well established that phonotactic probabilities, the likelihood of segments occurring in a given sequence, play a role in (early) language acquisition and processing (cf. Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993; Jusczyk, Luce, & Charles-Luce, 1994; Mattys & Jusczyk, 2001). Furthermore, it is well established that non-allophonic morphophonological alternations, such as the Dutch voicing alternation, are difficult for children to acquire (Van de Vijver & Baer-Henney, 2011; Van Wijk, 2007; Zamuner, Kerkhoff, & Fikkert, 2011). In this paper we investigate whether Dutch-learning children are able to use phonotactic probabilities of their input to predict, and therefore assist, the acquisition of voicing alternations.

Studies into the role of phonotactic probabilities in the developing lexicon have typically used perceptual paradigms, while acquisition of morphophonological alternations has predominantly been investigated from the perspective of the child's productions. We take the novel approach of combining these two views of the developmental process: we test both perception and production of voicing alternations by Dutch toddlers. Specifically, we investigate

[1] A version of this chapter has been submitted for publication

the relationship between toddlers' production of alternations in morphologically complex words, and their sensitivity to mispronunciations of voicing in the same words. We contrast voicing alternations in different phonological contexts, allowing us to examine the impact of phonotactic probability on the accuracy or robustness of voicing representations.

From a young age infants are sensitive to phonotactic probabilities, also referred to in the literature as statistical frequency, phonological pattern frequency, subsyllabic frequency or segment probability. They are then able to use this sensitivity to aid their language learning. By nine months infants are sensitive to which combinations of sounds are legal in their ambient language (Jusczyk et al., 1993) and to the frequency of occurrence of different combinations of phonemes. They prefer to listen to non-words containing highly probable sound combinations rather than sequences with low phonotactic probability (Jusczyk et al., 1994), and can use this information to segment words from speech (Mattys, Jusczyk, Luce, & Morgan, 1999; Mattys & Jusczyk, 2001). In word learning tasks both children and adults are able to learn, retain and repeat items with high phonotactic probabilities faster and with greater accuracy than items with low phonotactic probability (Frisch, Large, & Pisoni, 2000; Hollich, Jusczyk, & Luce, 2002; Munson, 2001; Storkel & Rogers, 2000; Storkel, 2001; Treiman, Kessler, Knewasser, Tincoff, & Bowman, 2000; Vitevitch, Luce, Charles-Luce, & Kemmerer, 1997; Zamuner, Gerken, & Hammond, 2004). When phonological alternations occur in patterns of complementary distribution, such as allophonic variation, infants are able to use distributional learning strategies to rapidly learn the alternating pattern (Seidl, Cristia, Bernard, & Onishi, 2009; White, Peperkamp, Kirk, & Morgan, 2008).

In this paper we contribute to the existing literature by investigating whether Dutch toddlers are able to use phonotactic probabilities to aid their learning of voicing alternations. Dutch has a voicing contrast in syllable-initial position but the contrast is neutralised syllable finally. Only voiceless obstruents are attested in this position[2]. For example, the Dutch words *bed* 'bed' and *pet* 'cap' are minimal pairs, differing only in the voicing of the initial segment; [bɛt] and [pɛt]. If a morphological paradigm contains a voicing alternation (or has an underlying voiced obstruent), the voiced obstruent will surface before a vowel-

[2] Exceptions arise through assimilation to the following voiced obstruent, e.g. *dekbed*, 'quilt' is pronounced [dɛg.bɛt].

initial suffix because the stem-final obstruent is no longer in final position. The plural form of *bed* is [bɛdən][3] with the plural suffix *-en*. Not all morphological paradigms contain voicing alternations; the final [t] of *pet* remains voiceless in all word forms, e.g. *petten,* [pɛtən]. Because voicing alternations do not occur in complementary distribution they are reportedly difficult to acquire (Peperkamp & Dupoux, 2002; Pierrehumbert, 2003).

Evidence from both spontaneous and elicited production data supports the claim that non-allophonic voicing alternations pose difficulties for children (Kager, 1999; Kerkhoff & De Bree, 2005; Kerkhoff, 2007; Van de Vijver & Baer-Henney, 2011; Van Wijk, 2007; Zamuner et al., 2011). In a plural elicitation task, Kerkhoff (2007) found that at 7 years of age children achieve only 57% accuracy in productions of plurals with a voicing alternation. In 41% of their responses they produced a devoicing error, e.g. *bedden* as *[bɛtən]. Conversely, they made voicing errors in only 2% of their responses for non-alternating words e.g. *petten* as *[pɛdən]. Younger children at three to five years of age also participated in this study and their accuracy scores were even lower than those of the 7-year-olds. A possible explanation for children's difficulty may be articulatory in nature: that they do not have the ability to reliably produce a voicing contrast in medial position. This is not the case, however, given that Zamuner, Kerkhoff and Fikkert (2011) demonstrated in an imitation task that 3-year-olds are able to produce both [t] and [d] word-medially. A more likely explanation is representational: children simply do not yet have a reliable representation of whether a voicing alternation occurs in a paradigm or not, but do know that the plural is formed by suffixing –*en* to the stem. Without knowledge of alternations they adhere to a principle of Paradigm Uniformity, assuming that all surface realisations within a morphological paradigm have identical values for a given property (cf. Steriade, 2000 and references therein).

In this paper we investigate 3-year-olds' productions and perception of voicing alternations in plural forms. By this age Dutch-acquiring children are competent users of plural morphology (Schaerlaekens, 1977; Van Wijk, 2007; Zonneveld, 2004), but make frequent errors in voicing alternations (Kerkhoff,

[3] Note that the final [n] is often deleted in speech, but this does not impact on the argument here.

2007; Zamuner et al., 2011). Schaerlaekens (1977), Van Wijk (2007) and Zonneveld (2004) report that plural marking first appears in Dutch children's speech at around 18 months of age, therefore by three years old most children should have little difficulty in forming the plural of known words. Reported age of acquisition of the plural in Dutch is in line with the acquisition of the plural in other languages (Berman, 1981; Bittner & Köpke, 2001; Cazden, 1968; de Villiers & de Villiers, 1972; Mervis & Johnson, 1991; Park, 1978; Ravid & Schiff, 2009; Raymond, Healy, McDonnel, & Healy, 2008). Perception studies have also indicated that by 3 years old children are well able to comprehend plural markers (Jolly & Plunkett, 2008; Kouider, Halberda, Wood, & Carey, 2006). Despite using and comprehending plural morphology, children's productions of voicing alternations in frequently occurring, familiar words are often inaccurate (Kerkhoff & De Bree, 2005; Kerkhoff, 2007; Zamuner et al., 2011). Experiment 1 focuses on 3-year-olds' production (in)accuracies, and Experiment 2 investigates whether their perception abilities are advanced of their production with regard to voicing alternations.

Different theories exist to explain morphology and how complex words and morphophonological alternations are represented in the mental lexicon. Theories of morphological and morphophonological acquisition accordingly reflect these different points of view. The "final-devoicing" view assumes that speakers represent bare stems in their lexicon with a final voiced segment. A rule or constraint system mediates between the underlying representation and surface form, ensuring that if the stem occurs in a context where voicing is not permitted, the final segment will be devoiced (for Dutch see Booij, 1995). It is assumed that morphology is transparent, and complex forms are decomposed into stems and morphemes for lexical access. These decomposed elements are represented independently from one another in the mental lexicon (cf. Albright & Hayes, 2003; Taft & Forster, 1975). Alternatively, rote-storage theories, for example usage-based (e.g. Bybee, 2001) or connectionist (e.g. Rumelhart & McClelland, 1986) models propose that all surface forms, whether morphologically simple or complex, are represented in the lexicon, e.g., [bɛt] and [bɛdən]. These theories claim that rules, such as a rule of final devoicing, are useful descriptions of generalisations but are not psychologically real. They see no reason to assume an underlying representation that differs from the surface form, and there is no need for a rule of final devoicing as the final segment of the singular form is represented without voicing. A third group of theories, so called "dual-route" theories propose that both decomposition and whole-form storage are possible, and one does not exclude the other (Baayen, Dijkstra, & Schreuder, 1997; Clahsen, 1999; Marcus, 1995; Pinker, 1991).

Despite differences in theoretical views of how complex word forms and voicing alternations are represented in the mental lexicon, there are a number of similarities in how the acquisition process may progress, particularly during the early stages of acquisition. Hayes (1999), Peperkamp and Dupoux (2002) and Tesar and Prince (2003) all propose decomposition-based mechanisms. Peperkamp and Dupoux (2002) apply rules and Hayes (1999) and Tesar and Prince (2003) an Optimality Theory framework. All propose that infants are initially unaware of morphological complexity and treat all words as separate lexical items. At this point they can rapidly use statistical learning mechanisms to deduce that there must be a phonotactic constraint against voiced obstruents in final position, however, without morphological knowledge they have no choice but to assign underlying representations that are true to the surface form, for example representing *bed* as /bɛt/ and *bedden* as /bɛdən/, where *bedden* is not parsed as morphologically complex. Once morphologically aware the infant has the skills to notice intraparadigmatic relationships based on semantic and phonological overlap and can re-asses whether a stem-final voiceless segment is underlyingly voiced or not, for example that [bɛt] may be derived from the abstract representation /bɛd/. Initial learning proceeds in a similar manner, even if morphological decomposition is not presumed to be the mature state. When intraparadigmatic relationships become apparent to the infant, instead of decomposing forms and assigning an underlying representation links between the whole-word forms of the paradigm will be established; [bedə] is the plural of [bət]. Both theories require the learner to have encountered both simple and complex forms in order to know whether a paradigm contains an alternation or not. The difficulty in acquiring this system lies in the fact that the voicing is contrastive, or phonemic, in Dutch.

Explanations, such as those of Hayes (1999), Peperkamp and Dupoux (2002) or Tesar and Prince (2003), assume that the presence of a voicing alternation is not predictable, and this is why the system is so difficult to acquire.

If there is an equal chance of a stem-final [t] alternating or not, then indeed the child must rely solely on lexical and morphological information. Corpus data from Dutch adult- and child-directed speech reveals that the chance of an alternation occurring within a morphological paradigm is not random, but is predictable on the basis of the quality of the preceding segment in the word. Adults have been shown to make use of this information (Ernestus & Baayen, 2003, 2004; Sebregts & Strycharczuk, 2012), and we hypothesise that children are also able to do so.

Ernestus and Baayen (2003) accessed the CELEX corpus to investigate the probability of a stem-final obstruent alternating or not. They examined 1697 words with a base morpheme ending in an obstruent which has both a voiced and voiceless variant in Dutch, followed by a vowel-initial suffix. Nouns, verbs and adjectives were included in their sample, including the plural noun suffix *–en* as well as the infinitive verb suffix *-en* and the comparative adjective suffix *-er*. Overall, they found that a stem-final [f] is most likely to be alternating, with 70% alternations. [p] is least likely to alternate, with only 9% of words ending in an underlyingly voiced segment. [t] is more likely to be non-alternating than alternating, with 177 tokens (25%) alternating and 542 tokens (75%) non-alternating. Furthermore, using a k-nearest-neighbours algorithm and information gain weightings (TiMBL, Daelemans, Zavrel, Van der Sloot, & Van den Bosch, 2002) they established that the likelihood of a stem-final obstruent alternating or not is further predictable from its phonological context, specifically the presence and quality of a preceding consonant; uncertainty about the voicing status of a final obstruent decreases when other phonological properties of the stem are known. Crucially for our purposes, if the place and manner of articulation of the final obstruent was known, the model was able to correctly predict the alternation status of a stem-final obstruent in 76% of cases. If vowel quality and presence and quality of the preceding consonant are also taken into account, there is a significant further improvement, to 83%.

Corpus Analysis of Child-Directed Speech

We conducted an analysis of Dutch child-directed speech comparable to the analysis of Ernestus and Baayen (2003) and found similar distributional patterns of alternating and non-alternating stem-final obstruents as attested in adult language, indicating that the child's input provides them with information about the predictability of voicing alternations in different phonological contexts. Through the CHILDES database (MacWhinney, 2000) we accessed all transcripts within the CLPF (Fikkert, 1994; Levelt, 1994) and Van Kampen corpora (Van Kampen, 1994) where the child was 3;6 or younger[4]. We extracted all items for which there was both a singular and plural token in the corpus where the stem had a final [t] or [p] and the plural is formed with the suffix *–en*. 40 of the 57 word types in our analysis contained a coronal plosive (21 alternating) and only 17 a labial plosive (1 alternating). The upper age-limit of the corpus analysis corresponded to the age of the children participating in our experiments. Reported token counts in this analysis refer to the plural form, as this form provides information about voicing alternations.

Table 1

Proportion of singular-plural pairs in CHILDES corpus containing a voicing alternation.

Singular-Plural pairs		*Alternating*	
Types	Tokens	Types	Tokens
57	493	22 (38.6%)	158 (32%)

The corpus analysis was restricted to coronal and labial plosives because these segments provide the most reliable source of information about voicing in Dutch. The velar plosive is not informative as /g/ is not a native phoneme, therefore there is no [k]~[g] alternation. Fricatives, belonging to the class of obstruents, should also be a source of information about voicing alternations, however, fricative voicing is unreliable in Dutch and for speakers in many parts of the Netherlands the voicing contrast has been neutralised (Ernestus, 2000; van de Velde, Gerritsen, & van Hout, 1996).

Although there are two productive plural suffixes in Dutch, *-en* and *–s*, we only considered *–en* in our analysis. The choice of suffix in Dutch is largely phonologically driven (Booij, 1995), with *–en* preferred following an obstruent or diphthong, or if the stem has final stress. *–s* is preferred if the stems ends in a

[4] Transcripts

CLPF corpus: all transcripts. Van Kampen corpus: laura01-laura41, sarah01-sarah34.

vowel or unstressed syllable (see Booij, 1995 for more details). As only *–en* triggers voicing alternations, we excluded stems that take *–s* from our analysis.

Taking the 57 singular-plural pairs in our corpus, we looked at the properties of the preceding segment as an indication of the predictability of the alternation status of the stem-final obstruent. The results of this analysis are presented in Table 2. Considering token frequency there is a striking difference in the likelihood of a final obstruent alternating in a morphologically complex form. When preceded by a vowel (short or long), there is a 35-40% chance that the obstruent will alternate, and accordingly, there is a 60-65% chance that it will not alternate. If the obstruent is preceded by a sonorant consonant, either a liquid or nasal, the chance of a stem-final obstruent alternating increases to 70-80%.

Table 2

Distribution of stem-final alternations in singular-plural pairs in a corpus of CDS.

Preceding segment	*Types: % alternating*	*Tokens: % alternating*
short vowel	39	39.5
long vowel	23.6	34.5
nasal	21.9	80.8
liquid	9.5	69.8
fricative	5.9	0

In laboratory experiments with adult Dutch speakers, Ernestus and Baayen (2003) and Sebregts and Strycharczuk (2012) have shown that knowledge of phonotactic sequencing information is indeed used to predict voicing alternations. Both studies used a similar task, but whereas Ernestus and Baayen (2003) required participants to provide a written response Sebregts and Strycharczuk (2012) required a spoken response. Participants heard a novel verb form in the first person singular, *ik x*, a position where the stem final obstruent is voiceless, and had to provide the past tense form. The past tense is formed by suffixing either *-te* [tə] or *-de* [də] to the stem, where the stem and first person singular form are identical. The choice of suffix is phonologically controlled; if the stem final obstruent is underlyingly voiced the appropriate suffix is *-de*, and if voiceless *-te*. Thus, participants' choice of suffix reflects their interpretation of whether the paradigm contains a voicing alternation or not. Both studies show that adults rely on their knowledge of the phonotactics of other words in their lexicon when interpreting stem-final voiceless segments in novel words.

From both corpus and experimental studies with adult Dutch speakers we can thus conclude that the alternation status of a stem-final obstruent is predictable on the basis of the preceding segment, and adult speakers make use of this predictability. Corpus data from child directed speech indicate that children are exposed to the same lexical distributions in their input, and at some point in their development they must become sensitive to these properties. We predicted that Dutch 3-year-olds would already be able to make use of this cue. To test this we conducted a plural-elicitation task, manipulating whether the segment immediately preceding the stem-final obstruent was a vowel or sonorant consonant, to ask whether children's production of voicing alternations in known words is affected by phonological context. This approach has previously been used by Kerkhoff (2007) to investigate a similar research question concerning how the production of voicing alternations develops over time. We expected children to produce voicing alternations more accurately in the post-sonorant context than post-vocalic context.

In the post-sonorant condition we include the nasal /n/ and the liquids /l/ and /r/. Sonorants form a natural class in phonology; they are phonetically similar and exhibit similar behaviour (cf. Gussenhoven & Jacobs, 2005). The similarity of /n/, /l/ and /r/ in Dutch is apparent in our corpus analysis, where nasals and liquids clearly behave differently to vowels with respect to voicing alternations (cf. Table 2). Voicing alternations are more frequent following a liquid or nasal, and the opposite is true for vowels. It should also be noted that there is no r-vocalisation in Dutch. A word such as *taart*, 'cake', retains the consonantal element, even though the exact realisation varies geographically (Sebregts et al., 2003).

Experiment 1

Methods

Participants.

Data from 49 children were included in the analysis (*M* age: 37 months and 27 days, 24 girls). Twenty-seven children participated in the post-vocalic condition (*M* age: 37 months and 25 days, 14 girls). A further 13 children were tested in this condition but their data was excluded from the analysis because they did not produce a minimum of one token of both an alternating and non-alternating word of sufficient quality to be acoustically analysed after exclusion criteria had been applied ($n = 11$) (see Data Analysis below for details of exclusion criteria), or from lack of data due to a technical error ($n = 2$). Twenty-two children participated in the post-sonorant condition (*M* age: 38 months and 0 days, 10 girls), and data from a further 17 children were removed from analysis because they produced less than one token of each an alternating and non-alternating word after applying exclusion criteria. Children were recruited through the Baby

Research Center of the Max Planck Institute for Psycholinguistics and Radboud University Nijmegen.

Materials.

The stimuli in each condition consisted of 16 nouns with a stem-final [t] that take the plural suffix *–en.* Eight nouns contained a voicing alternation in the plural, and eight did not. The following criteria were used to select target words: (1) they should be easily depictable; (2) they should be familiar to children of this age; (3) targets should have a higher token frequency in the singular than the plural.

Criterion 2 was addressed by selecting items that appear in the Dutch version of the MacArthur Communicative Development Inventory (Zink & Lejaegere, 2002). This list, however, does not contain information about inflected forms of specific words, so we also took data from corpora of children's speech. Using the CHILDES database (MacWhinney, 2000) we accessed all transcripts from the CLPF (Fikkert, 1994; Levelt, 1994) and van Kampen (Van Kampen, 1994) corpora where the child was under 3;6. These were the same transcripts as studied in the corpus analysis reported in the introduction. In addition to the child directed speech included there, we now included utterances by the child as well. We assumed that if a word appears in the corpus it is likely to be at least minimally familiar to the 3-year-olds participating in our experiment. In addition to selecting items that should be familiar to all children, we also used parental reports to gauge individual children's familiarity to each item. One week before participating in the experiment parents were sent a picture book and accompanying questionnaire. The book contained 64 colour images and the orthographic form of the intended referent. All items appeared in either Experiment 1 or 2 as targets, distractors or fillers, and the images were the same colour photographs that would be used during the experiments. In the book all items were presented in the singular. This was to avoid drawing attention to the experimental question and because we were interested in whether the target items formed part of the child's vocabulary. Parents were asked to read the book together with their child and indicate, in a similar manner to the MacArthur Communicative Development Inventory (Fenson et al., 1993), which words their child said and which words they understood but did not produce. In addition we asked them to indicate whether their child recognised the image as its intended referent. If a parent indicated that their child produced, comprehended or recognised the picture as its intended referent we concluded that the word was familiar to the child. Unfamiliar items were not included in the analysis.

Criterion 3, that the singular should be more frequent than the plural, ensured that children should be aware of the morphological link between singular and plural forms, and that the plural form is morphologically complex. It has been hypothesised that children do not interpret highly frequent plurals, for example *tanden* ‘teeth’, as morphologically complex, but instead treat them as non-decomposable units (cf. Tesar & Prince, 2003). Frequency counts were obtained from the web-based CELEX lexical database (http://web.phonetik.uni-frankfurt.de/simplex.html[5]; Baayen, Piepenbrock, & Van Rijn, 1993). Two items in the post-vocalic condition, *noten* ‘nuts’ and *botten* ‘bones’, violate this criterion but were nonetheless included as they fulfilled all the other criteria better than other possible test items. Furthermore, the item *botten* has two related meanings depending on the context or audience. The more frequent usage in adult language refers to the bones of the skeleton, whereas the child’s use of the word refers to a dog’s bone. This difference is apparent in the CHILDES analysis, where the plural form does not occur but the singular form occurs seven times.

[5] Thanks to Henning Reetz for making this web interface available.

Table 3

Frequency information and canonical pronunciation of plural stimuli in Experiments 1 & 2

Word Type	*Item*		*Gloss*	*CELEX Freq.*		*CHILDES Freq.*		*Yoked distractor*	*Distractor gloss*
				sl.	*pl.*	*sg.*	*pl.*		
Post-vocalic [t]	botten	[bɔtən]	bones	314	590	7	0	bomen	trees
	fluiten	[flœytən]	flutes	201	30	41	22	fietsen	bikes
	noten	[noːtən]	nuts	379	402	5	1	neuzen	noses
	petten	[pɛtən]	caps	698	97	17	1	peren	pears
Post-vocalic [d]	bedden	[bɛdən]	beds	12052	499	258	2	boeken	books
	broden	[broːdən]	breads	2616	99	79	2	brillen	glasses (pl.)
	hoeden	[huːdən]	hats	1314	186	174	2	handen	hands
	kleden	[kleːdən]	rugs	455	67	2	0	klokken	clocks
Post-sonorant [t]	kaarten	[kaːrtən]	maps	3742	1502	36	23	kaarsen	candles
	olifanten	[olifɑntən]	elephants	428	176	191	37	ooievaars	storks
	taarten	[taːrtən]	cakes	437	43	60	1	tafels	tables
	tenten	[tɛntən]	tents	1141	279	27	0	tenen	toes
Post-sonorant [d]	eenden	[endən]	ducks	1013	404	174	10	eekhoorns	squirrels
	manden	[mɑndən]	baskets	827	205	22	0	manen	moons
	paarden	[paːrdən]	horses	6675	2325	357	25	poezen	cats
	zwaarden	[zwaːrdən]	swords	650	123	1	0	zwembandjes	water wings

Note. The columns Yoked distractor and Distractor gloss are relevant for Experiment 2 but not Experiment 1

For the experiment, one image of the target was printed on the centre of a card approximately 10cm square and laminated. All images were printed in colour on a grey background, and two cards were made per item. A piece of Velcro was affixed to the reverse of each card allowing them to adhere to a soft surface. Per condition there were 14 pairs of cards: eight were test items and six were filler items. The filler items were *auto* ('car'), *bal* ('ball'), *hand* ('hand'), *oog* ('eye'), *poes* ('cat') and *sleutel* ('key'). In the post-sonorant condition the filler *hand* was replaced by *kikker* ('frog') because *hand* contains the target context. These items occur in the earliest lists of words learned by children and 3-year-olds they should have little difficulty in labeling them in both the singular and plural.

Procedure.

Prior to the start of the experiment one card from each pair was attached to a freestanding board in a grid pattern at a height accessible to a small child. The remaining cards were placed in a small drawstring bag. During the experiment the experimenter sat or knelt on the floor and the child stood. A digital voice recorder (Olympus WS-650S) was placed on the floor at the base of the board. The child was instructed to take a card from the bag, find the matching picture on the board and hang their card next to the original. They were encouraged to label the card whilst looking for the matching card, and once they had found the pair they were encouraged to use the plural form, e.g. "Well done, now you have two...". Once the child had hung all pictures on the board they were asked to name the pairs once more.

Data Analysis.

Responses were recorded on a digital voice recorder and edited in *Praat* (Boersma & Weenink, 2011). All files were transcribed by hand to identify the position of target words within the recording session. Plural target forms were extracted and the quality of the recording was judged. Due to the nature of the task a number of tokens had to be removed because of poor recording quality, for example, if the child jumped or pulled a card from the board their speech was masked.

In this analysis we were specifically interested in the pronunciation of word-medial voicing, rather than the acquisition of plural morphology. For this reason we did not include tokens where the child produced a plural form that differed from our expected target, for example by producing a different lexical item or using the diminutive suffix. The diminutive suffix *–je* is highly productive in Dutch, particularly in child and child-directed speech and the plural form of a diminutive always takes the suffix *–s* (and not *–en*). Some children seemed to use this as a strategy if they are unsure of the correct plural allomorph, for example they would use the singular non-diminutive form *eend* ('duck'), but then the diminutive plural, *eendjes*. These forms do not match the phonological context that we are interested in as an alternation never occurs in this position, and we did not include them in our analysis.

Accuracy of children's productions of voicing was judged by three adult Dutch native-speakers with some training in phonetics. To reduce possible effects of lexical bias (cf. Ganong, 1980), adults were presented with only the medial VCV or VNCV from the child's production (e.g. *bedden* became *edde*). Targets were spliced to include 75% of the vowel duration, thereby providing enough information about the vowel quality but reducing lexical information that may be gained from co-articulation effects, for example, formant transitions between the initial segment and vowel. In a quiet room coders listened to each token over good quality, closed, headphones (Sennheiser HD 215) and in a forced choice task indicated whether they heard a [t] or [d]. They also had to indicate, on a five-point scale, how sure they were of their response. The certainty measure was predominantly used to gauge the quality of the recording, and to remove cases where the child produced something other than [t] or [d]. All coders agreed that they could not recognise the original lexical item from the VCV segment.

Because adult listeners are sensitive to phonotactic sequencing, we were concerned that their lexical knowledge would bias them towards [d] judgments following a sonorant consonant and [t] following a vowel. As this would work in favour of our experimental hypothesis we needed ensure that the adults were able to make unbiased judgments. We recorded five (different) adult speakers producing all 16 target plural forms in a similar situation to the children. Adults were presented with pictures of individual items and asked to produce the plural form. Recordings were made using the same recording device in a quiet office with a similar level of background noise to the Baby Research Center. Adults were assumed to accurately produce a [t] or [d] in each token. Their tokens were spliced and judged by the coders in the same way as the children's tokens. Two of the three coders accurately classified voicing in all 80 of the adult tokens and the third made one error (accuracy = 99%). These high accuracy scores indicated that coders could reliably base their decisions on the acoustic stimuli and were not subject to lexical or other perceptual biases.

Tokens from children's data were included in the analysis if all three adult coders perceived the same voicing value[6]. Of 361 tokens with good quality audio recordings, all three coders were in agreement on 305 tokens. Disagreement was spread across coders, that is, there was not one coder who consistently disagreed with the other two. A further twelve tokens were removed because the child no longer contributed at least one alternating and one non-alternating token.

Results

Accuracy of children's productions was assessed using a logistic regression analysis. Predictors of production accuracy were Target Voicing (/d/ or /t/), Phonological Context (post-sonorant or post-vocalic) and the interaction of these two factors. The reference levels were voiced and post-sonorant. Random intercept terms were included for Subject (*SD* = 0.85) and Item[7], although Item was not necessary as item accounted for effectively no variation. The model was run in R (R Core Team, 2012) using the lmer function from package lme4 (Bates, Maechler, & Bolker, 2013) and defined as: *Production Accuracy ~ (Target Voicing * Phonological Context) + (1 | Item) + (1 | Participant). P*-values below .05 were considered significant, and between .05 and .1 were considered marginally significant.

293 tokens from 49 participants were included in the analysis, with each participant contributing an average of 6 tokens (range: 2-13). The data set is

[6] Including tokens where coders disagreed did not change the overall pattern of results.

[7] Some propose the necessity for random slopes for all within-unit factors (Barr, Levy, Scheepers, & Tily, 2013). In our data set this would mean including a random slope term for Subject by Target Voicing. Inclusion of this term does not affect the pattern of results.

broken down by voicing and phonological context in Table 5 (by-item results are presented in Appendix I).

Table 4

Results of Experiment 1: Production accuracy by phonological context and voicing.

Condition	*Voicing*	*No. Tokens*	*No. Accurate tokens*	*Accuracy rate (%)*
Post-vocalic	/t/	86	83	96.5
	/d/	77	18	23.4
Post-Sonorant	/t/	73	60	82.2
	/d/	57	22	38.6

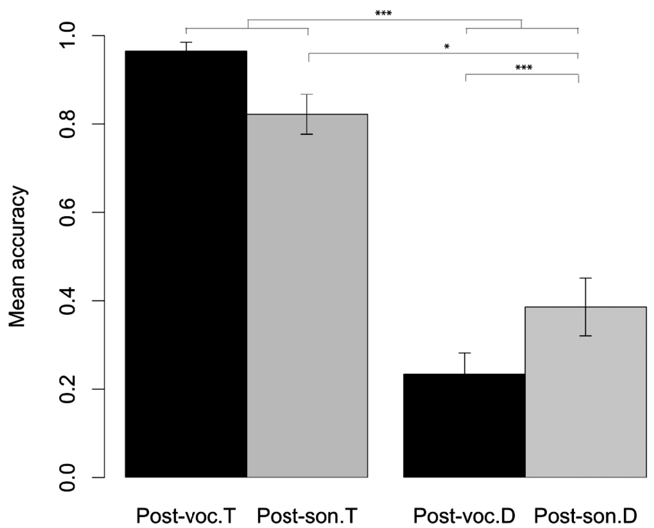

Figure 1. Production accuracy by phonological context and voicing

Production accuracy in the post-sonorant condition was significantly influenced by voicing and phonological context. Alternating words were produced with an accurate [d] more often in the post-sonorant condition than post-vocalic condition (main effect of Phonological Context: β= -0.96; *SE*= 0.49; $p < .05$). In the post-sonorant context, words with no voicing alternation (i.e. target is [t]) were produced more accurately than words requiring a voicing alternation (main effect of Target Voicing: β= 2.28; *SE*= 0.43; $p < .001$). The interaction of Target Voicing and Phonological Context was also significant, indicating that the difference in production accuracy between post-vocalic and post-sonorant words is smaller for alternating words than non-alternating words ($\beta = 2.8$; $SE = 0.85$; $p < .001$). Thus we find a step-wise pattern of accuracy: post-vocalic /t/ > post-sonorant /t/ > post-sonorant /d/ > post-vocalic /d/. Phonological context is an informative cue for the presence or absence of intra-paradigmatic voicing alternations, and Dutch 3-year-olds are sensitive to this cue.

Table 5

Effects of voicing and phonological context on children's accuracy of producing stem-final obstruents in plural forms.

	Estimate	*Std. Error*	*z value*	*Pr(>|z|)*
(Intercept)	-0.5	0.34	-1.44	.15
Voicing (d vs. t)	2.28	0.43	5.29	< .001 ***
Phonological Context (sonorant vs. vowel)	-0.97	0.49	-1.99	.046 *
Voicing * Phonological Context	2.8	0.85	3.3	< .001 ***

Note. ***$p < .001$. **$p < .01$. *$p < .05$. . $p < .1$

Discussion

As predicted, children were more accurate in their productions of word-medial voicing in plural forms when there was no voicing alternation between the stem and plural form. Another way of formulating this is to say that children made more devoicing errors in alternating forms than voicing errors in non-alternating forms. This result is in line with previous plural elicitation tasks with Dutch children (Kerkhoff & De Bree, 2005; Kerkhoff, 2007; Zamuner et al., 2011). We were particularly interested in how children's accuracy of voicing in alternating words was affected by phonological context, and hypothesised that they would be more accurate, making fewer devoicing errors, in a post-sonorant context than post-vocalic context. Our results indicate that children are paying attention to phonological context. As predicted on the basis of adult experimental data and child-directed speech corpus data, children produce a [d] more accurately in words where it is preceded by a sonorant than a vowel, indicating that they are making use of phonotactic probabilities in determining whether a stem-final [t] alternates in the plural or not.

If children are sensitive to the frequency of alternations following a nasal, the reverse can also be predicted, that children may overapply their knowledge of phonological context and alternations. They may have a bias for post-nasal voicing and produce more voicing errors in non-alternating forms when preceded by a sonorant than by a vowel. This prediction is also upheld in our data; children had a mean accuracy score of 97% for post-vocalic, non-alternating words, and 82% for post-sonorant, non-alternating words. That is, voicing errors of the type **fluiden* occur in 4% of tokens, and of the type **tenden* in 18%.

Our data produce a stepwise pattern of accuracy; VT > NT > ND > VD (where V refers to any vowel, N to any sonorant, and T and D to non-alternating and alternating respectively). This order is not a direct translation of frequency patterns as established in our corpus analysis of child-directed speech (see Table 2). Taking token frequency in children's input from high to low the order is; ND > VT > VD > NT. Our elicited production data show that three-year-olds are not yet certain about which nouns in their lexicon contain a voicing alternation in the plural. They make frequent errors, in particular devoicing errors in alternating forms. They have an overwhelming preference to not produce a voicing alternation and to form the plural by affixing the suffix -*en* to the stem, but the high frequency of alternations in the post-sonorant context encourages them to overcome this bias. Although they still have an error rate of 61% for post-sonorant alternating forms, this is significantly lower than the error rate of alternating forms in the post-vocalic context.

Usage-based theories predict that lexical frequency is crucial to acquisition of morphophonological alternations. Counter to the results of Kerkhoff (2007), in our data we find no correlation between production accuracy of individual items and either CELEX frequency counts (Pearson: $r = .02$, $p = .9$) or CHILDES frequency counts (Pearson: $r = .18$, $p = .5$). This supports the hypothesis that segmental pattern frequencies are guiding children's production accuracy, and this outweighs the contribution of lexical item frequency. Previous research has shown the effect of phonotactic, sublexical, frequency on children's spoken language. Children are faster to learn non-words containing high probability sequences (Storkel, 2001), and in non-word repetition tasks they produce high probability sequences more fluently and accurately (Edwards, Beckman, & Munson, 2004; Munson, 2001).

The role of ease of articulation must be taken into consideration when evaluating these results. Articulatory accounts would predict that voiced obstruents are more likely to be perceived in both the post-vocalic and post-sonorant condition. Voicing through the closure is an important cue for detecting word-medial voicing (Slis & Cohen, 1969). In order to produce a voiceless obstruent the speaker must actively stop glottal fold vibrations. The relative timing of articulator movement may result in some degree of voicing remaining through the closure. Articulatory effects are exacerbated post-nasally, an environment where voicing is reported to be phonetically natural (cf. Kager, 1999). The lowered velum required for the nasal must be raised for the obstruent, but if the velum is not fully raised before the onset of the obstruent some air may flow through the nasal cavity. This "nasal leak" can be perceived as voicing (Hayes & Stivers, 1995). However, in a word-imitation task previous production data from Dutch 3-year-olds has revealed that they have little difficulty in producing word-medial voiced or voiceless segments, and actually produce voiceless segments more reliably than voiced obstruents (Zamuner et al., 2011). In our data, if articulatory difficulties were driving the attested effects, we would expect to see greater accuracy of voiced segments than voiceless segments, or at least substantial voicing errors of voiceless targets, which is not the case. Neijt and Schreuder (2007) argue although voiced segments are easier to produce word-medially, when uttered by a child they may be perceived as voiceless because of the speed of the child's articulation. They claim that voiceless segments favour slow articulation, requiring longer periods of closure or aspiration than voiceless obstruents, and the slow speed of children's articulations may extend a voiced obstruent to the extent that an adult perceives it as voiceless. We do not believe that this is the major contributor to our results, as children were on the whole enthusiastic about the game and in many cases shouted the answer as quickly as possible. Of course not all children did this, indeed the opposite was true in some cases where children shouted the target word, extending their articulation. This resulted in a variety of speaking rate across tokens and is unlikely to be the primary reason for the [t]-bias in children's productions. Co-articulation effects and ease of articulation undoubtedly contributed to our data, but they cannot explain our results entirely, allowing us to conclude that paradigm uniformity, influenced by phonological context, is the driving factor in children's production accuracy of voicing in alternating and non-alternating plural forms.

Production studies provide only limited insight into the representations stored in the mental lexicon. As discussed, the role of articulatory control is important, and at a representational level the relationship between children's productive and receptive lexical representations is not yet well understood. As Swingley and Aslin (2000) discuss, the literature reveals a number of examples of children knowing more than they can say, and production data frequently underestimates children's abilities. A classic example is the *sip-ship* case (N. V. Smith, 1973) where the child says *sip* for *ship*, but rejects this form if produced by an adult. In Experiment 2 we investigated children's receptive lexical representations of voicing in alternating and non-alternating plural forms, and whether their performance in the production task provides an accurate reflection of their stored representations. Again we contrasted voicing alternations in a post-vocalic and post-sonorant context. The same children participated in both Experiments 1 and 2.

In Experiment 2 we used the Intermodal Preferential Looking Paradigm (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 2009) to measure children's sensitivity to mispronunciations of voicing in familiar words (Swingley & Aslin, 2000). This method provides insight into the phonetic specificity of representations stored in the mental lexicon. If the child is familiar with a word and has a detailed phonetic representation they will notice mispronunciations that deviate from their expectation, and this will be apparent in their gaze behaviour. We tested whether children are sensitive to mispronunciations of voicing in word-medial position of familiar plural forms, for example, *bedden* ('beds') pronounced as **betten*, or *petten* ('caps') as **pedden.*

Van der Feest (2007) used this paradigm to test the specificity of Dutch-learning children's representations of voicing in word-onset position. In this study they found an asymmetric pattern of results; infants were sensitive to mispronunciations that add voicing, for example, children did not accept **boes* as a good representation of the form *poes* ('cat'). However, they were not sensitive to devoicing mispronunciations, for example if the word *boom* ('tree') was presented as **poom* they looked equally long to the target image. This experimental paradigm has also been successfully applied to word-final and word-medial position (Bowey & Hirakis, 2006; Swingley, 2003, 2009).

Experiment 2[8]

In this experiment children were presented with mispronunciations of voicing in word-medial position in the same familiar plural forms as used in the production task. As in Experiment 1, phonological context was a between-subject factor, with mispronunciations occurring in either a post-vocalic or post-sonorant context. In addition, we also tested children's sensitivity to mispronunciations of word-medial voicing in monomorphemic, bisyllabic words. In these items the mispronunciation occurs in the same phonological context as the plural words, but because it is not at a morpheme boundary - a potentially alternating position - we expected children to have a robust representation of voicing in these words and successfully detect mispronunciations, e.g., **kedding* for *ketting* ('necklace') or **latter* for *ladder* ('ladder').

When hypothesising the outcome of this experiment there are a number of interacting factors that lead to different predictions depending on the relative weight each factor plays in children's lexical representations. The basic assumption of the paradigm is that if participants have a robust phonetic representation of a lexical item they will be sensitive to mispronunciations in its form. The most general prediction for our results was therefore that children would notice all mispronunciations; they would be sensitive to mispronunciations of voicing in both directions, in both phonological contexts, in both plural and monomorphemic words. However, there are a number of factors that may influence this general sensitivity.

Firstly, the role of voicing alternations within a morphological paradigm of plural words was expected to influence lexical specificity. In Experiment 1 we found that children have a strong tendency to adhere to Paradigm Uniformity, producing many devoicing errors in plural forms that should contain a voicing

[8] The post-vocalic context of Experiment 2 uses the same data as Experiment 1 of Chapter 3 of this thesis.

alternation. It is likely that their mental lexicon contains representations of plural forms that match to their own productions. Accordingly, we predicted that children would accept plural forms presented with a [t], whether this is the canonical pronunciation or not. They would be less sensitive to mispronunciations of /d/ to [t] in plural words than vice versa.

Secondly, the specificity of stem-final obstruents may be modified by phonological context. Production accuracy in Experiment 1 was modified by the frequency of voicing alternations occurring in different phonological contexts. Voicing alternations occur more often in a post-sonorant context than post-vocalically, and children were sensitive to this distribution. If this context sensitivity is reflected in the robustness of lexical representations, we predicted that children will have a more robust representation of plural forms with post-sonorant /d/ than post-vocalic /d/, and of post-vocalic /t/ than post-sonorant /t/. As such, they will display greater sensitivity to mispronunciations in alternating, post-sonorant plural forms than alternating, post-vocalic plural forms (i.e. **honten* is less acceptable than **betten*). In non-alternating plural forms the reverse is predicted, and mispronunciations will be less disruptive to word recognition in the post-sonorant context than post-vocalic (i.e. **pedden* is less acceptable than **taarden*).

Both of these predictions relate sensitivity to mispronunciations to morphophonological knowledge of plural words. The final hypothesis is not related to voicing alternations, but to acoustic cues in the perception of voicing. Therefore it makes predictions about children's sensitivity to mispronunciations of voicing in monomorphemic forms as well. Previous studies have shown an asymmetry in the direction of detection of voicing mispronunciations in word-initial position by Dutch adults (Van Alphen & Smits, 2004) and toddlers (Van der Feest, 2007). Obstruent voicing is marked by the presence of vocal fold vibration; in word-initial position this is pre-voicing, in word-medial position it is voicing throughout the closure phase. During word recognition listeners perceive a segment with vocal fold vibration as being voiced, but entertain the possibility that a segment with no voicing may be either voiced or voiceless. In a task similar to ours, Van der Feest found that Dutch children accept devoicing mispronunciations but not mispronunciations that add voicing. As the cue to voicing is similar in both word positions, we predicted that the same asymmetry may occur in our data.

Methods

Participants.

Data from 72 children were included in the analysis (mean age: 37 months and 29 days; range: 36 months and 29 days – 38 months and 25 days; 34 girls). 37 children participated in the post-vocalic condition (mean age: 37 months and 29 days; range: 37 months and 7 days - 38 months and 25 days; 19 girls) and 35 in the post-sonorant condition (mean age: 37 months and 28 days; range: 36 months and 29 days - 38 months and 17 days; 15 girls). A further three children participated in the post-vocalic condition and four in the post-sonorant condition but were excluded from the analysis for fussiness or not participating in at least 8 of the 16 test trials. The same children participated in Experiments 1 and 2, completing both tasks during a single, 30-minute session.

Materials.

In each condition the stimuli consisted of 16 bisyllabic nouns with word-medial /t/ or /d/. Half of the words were plural forms and half were monomorphemic (singular) forms. Mispronunciations were created by changing the feature voicing value of the word-medial, i.e. *petten* became **pedden* and *bedden* became **betten.* The plural items were the same as the items used in Experiment 1, and monomorphemic forms were selected that adhered to the same criteria. An additional criterion was included, namely that all mispronunciations should result in non-words.

Each target item was yoked with a distractor image that should be familiar to children of this age. The label of the distractor item had the same onset consonant to delay participants' ability to make a decision between the target and distractor until later in the word.

Table 6

Frequency and canonical pronunciation of monomorphemic stimuli in Experiment 2.

Word Type	*Item*		*Gloss*	*CELEX Freq.*	*CHILDES Freq.*	*Yoked distractor*	*Gloss*
Post-voc. [t]	boter	[boːtər]	butter	976	8	beker	cup
	gieter	[xiːtər]	watering can	39	25	glijbaan	slide
	ketting	[kɛtɪŋ]	necklace	524	13	kussen	cushion
	sleutel	[sløʏtəl]	key	1481	23	spiegel	mirror
Post-voc. [d]	ladder	[lɑdər]	ladder	506	16	lepel	spoon
	pudding	[pʏdɪŋ]	pudding	96	0	puzzel	puzzle
	ridder	[rɪdər]	knight	299	0	robot	robot
	schaduw	[sxaːdyw]	shadow	2233	8	schouder	shoulder
Post-son. [t]	groente	[xruntə]	vegetable	519	1	geld	money
	skelter	[skɛltər]	go-cart	0	0	skippybal	space hopper
	winter	[ʋɪntər]	winter	2775	6	windmolen	windmill
	wortel	[ʋɔrtəl]	carrot	1586	40	worst	sausage
Post-son. [d]	aarde	[aːrdə]	earth	6497	5	aardbei	strawberry
	panda	[pɑndɑ]	panda	94	21	papagaai	parrot
	vlinder	[flɪndər]	butterfly	442	66	vogel	bird
	zolder	[zɔldər]	attic	844	2	zomer	summer

Note. Information about plural items was presented in Table 3

Audio stimuli were produced by a female Dutch speaker in a child-directed manner. Recordings were made in a sound-treated recording booth and digitised at a sampling rate of 44.1kHz and resolution of 16 bits in Adobe Audition. Stimuli were edited using Praat (Boersma & Weenink, 2011). The duration and average pitch of each item are presented in Appendix II. Across items there were no systematic differences in the duration, $t(31) = -1.86$; $p = .07$, or pitch, $t(31) = 1.28$; $p = .21$, of correctly and incorrectly pronounced targets. Intensity was equalised to 65 dB.

The visual stimuli were photographs of objects on a grey background presented side by side on the 17-inch TFT monitor of a Tobii T60 eye tracker. A thin black vertical line divided the screen in two, and each photograph was positioned in the middle of one half of the screen. In plural trials the visual display consisted of two identical images side-by-side. Plural images were the same images as used in Experiment 1. Three adult native Dutch speakers verified that all images were typical exemplars of the labeled category as would be understood by a young child.

Procedure.

The procedure was identical for children participating in the post-vocalic condition and the post-sonorant condition. During the experiment children sat on their caregiver's lap 60cm away from the Tobii monitor in a dimly lit room. The caregiver wore closed headphones and listened to music interspersed with speech throughout the experiment to mask the auditory stimuli and minimise any potential influence on their child's behaviour. Auditory stimuli were presented via centrally located loudspeakers below the screen. Stimuli were presented using Tobii-Studio software. The test began with a nine-point calibration procedure. If all points were not calibrated in the first attempt, individual points were recalibrated a second time. The experiment began immediately after calibration.

Each child was presented with four blocks of eight trials. Half of the trials were test trials, and half were filler trials. Of the sixteen test trials, the target was correctly pronounced in eight trials and mispronounced in the other eight. Filler items were assumed to be familiar to children of this age, and were always correctly pronounced. The presence of filler trials increased the ratio of correct pronunciation to mispronunciation trials to 3:1. Filler trials were not analysed.

In both the post-vocalic and post-sonorant condition the child was presented with all sixteen target items exactly once in either its correct or mispronounced form (eight plural items and eight monomorphemic items). No image or label was repeated. Thus, no child was presented with the same target item in both a correct and mispronounced form. Mispronunciations were balanced for direction (/t/ to [d] or vice versa) across all word classes. Table 7 displays an example of the distribution of target trials to one child in the post-vocalic condition. Six different versions were created, ensuring that all target items occurred equally as correctly pronounced and mispronounced trials across all participants.

Table 7

Example distribution of correctly pronounced and mispronounced target trials, post-vocalic condition. Shaded items indicate mispronunciations.

Plural [t]	*Plural [d]*	*Monomorphemic [t]*	*Monomorphemic [d]*
botten	bedden	boter	ladder
fluiten	broden	gieter	pudding
noten	hoeden	ketting	ridder
petten	kleden	sleutel	schaduw

Prior to each trial a fixation cross was displayed in the centre of the screen for 500ms. Target and distractor images were displayed on screen for 1600ms before the child heard *kijk!* ("look!"). 900ms later, or 2500ms from the trial begin, the target word was presented. The trial ended after a further 2500ms.

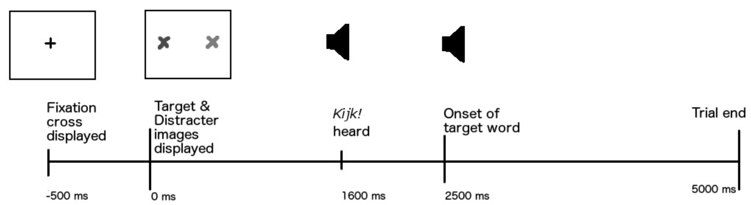

Figure 2. Time-course of a typical trial

Data Analysis.

A number of criteria were applied to ensure the data analysed were a reliable reflection of the child's linguistic abilities. Firstly, individual unreliable measurement points were removed. The eye-tracker assigns each measurement point a validity code of between 0 and 4, indicating the quality of the gaze data that has been recorded. 0 indicates that the system is certain of its measurement, 4 that the data is missing or definitely incorrect. Following the recommendation of the manufacturer ("Tobii Studio 1.X User Manual," 2008), measurement points with a validity code of 2 or higher were removed from analysis. This includes points where the child was not looking to the screen and the eye tracker could not measure their gaze behaviour, or points where the tracking quality was poor.

Secondly, data from whole trials were removed if the child was not participating in the task at that moment. We removed trials according to predefined criteria: (1) if the child did not look to the screen at all during the trial; (2) if they did not look to both displayed images during the 2500 ms prenaming window; or (3) if they did not look to either the target or distractor for at least 100 ms in the 2500 ms after the target onset.

Thirdly, trials were removed on the basis of parental report. As described in Experiment 1, prior to coming to the lab parents were sent a picture book and word list to fill in, noting whether their child understood or produced the word, and whether or not their child recognised the picture as its intended referent. If the answer to at least one of these questions was 'yes' we assumed that the word was familiar to the child. We removed trials from the analyses in which the child was unfamiliar with either the target or yoked distractor. 187 trials were removed for this reason.

The final criterion applied was to remove the participant from further analysis if, following all exclusion criteria, there were fewer than 50% of test trials remaining for analysis (fewer than 8 out of 16 trials). Data from seven children were removed for this reason. On average each child contributed 12.6 trials, out of a possible 16, to the analysis (*SD* = 2.4, range = 8-16). Appendix III provides the distribution by lexical item of items remaining for analysis.

Looks to the screen were coded for whether they were looks to the target or distractor in a given trial. A gaze point was calculated as the average of the x and y coordinates of the left and right eyes. Two areas of interest (AOIs) were defined in the display, covering most of the screen. An AOI corresponded to half of the display minus a 10 pixel-wide vertical line down the centre of the display. These large AOIs allow for variability in children's looking behaviour or slight miscalibration of the eye tracker, giving the maximum likelihood that a look to the screen is interpreted in the analysis as an informative look. As there was nothing else visible on the screen except the two pictures it was assumed that the child had no reason to be looking elsewhere within the display. The centre line was not included to reduce chance of overlap between left and right fixations. Fixations falling within either of the AOIs were considered object fixations. The few fixations falling outside either AOI were regarded as off screen and not taken into consideration in the analysis.

Differences in children's gaze behaviour in different trials were quantified using Growth Curve Analysis (GCA) with orthogonal polynomials. GCA is a multi-level modeling framework designed to analyse change over time at group and individual levels (Singer & Willett, 2003), where time could be measured in months or milliseconds (see Mirman, Dixon and Magnuson, 2008 for details of this method as applied to eye tracking data).

The time window for analysis was 1300 ms in duration, starting at the onset of the target word. Using GCA we do not have to delay the start of the analysis window to allow time for an eye movement to be made, driven by children's response to the target word as the model can indirectly take the onset of the slope into consideration. Accordingly, the time window is comparable to a traditional analysis that takes a window of analysis from 367-1367 ms after target word onset (e.g., van der Feest, 2007). The end of the time window of analysis corresponds to the point where children have fixated on the target and before they look away.

GCA captures the pattern of the gaze behaviour data using two hierarchically related submodels. The first submodel, Level 1, captures the effects of time on fixation proportions using third-order orthogonal polynomials. The intercept term reflects average height of the curve, analogous to an average measure of looks to target used in a traditional analysis. The linear term reflects a monotonic change in fixation proportion (a straight line). The third-order polynomial is necessary to capture the S-shape of the data.

The Level 2 submodel captures the effects of experimental manipulation on the Level 1 intercept and linear time terms. Fixed effects of Pronunciation (correct or mispronounced), Morphology (plural or monomorphemic) and Target Voicing (canonical voiceless or voiced), and an interaction of these three effects were included. The reference levels were correct pronunciation, plural and underlyingly voiceless. Effects of experimental manipulation on all Level 1 time terms were not included as the cognitive interpretation of such effects is unclear (Mirman et al., 2008).

The Level 2 submodel also includes random effects for individual participants and items. We included random effects of participant and item on all four time terms, despite the statistical cost, allowing for variation in each individual's intercept, slope and curvature. Random effects of participant accounted for individual differences in the time taken by participants to initiate a linguistically driven eye movement and the speed with which they shift their gaze to the target. Random effects for item accounted for variation in the timing of the crucial obstruent relative to the word onset.

The model was run in R (R Core Team, 2012) using the lmer function from package lme4 (Bates et al., 2013). The model was defined as: *OnTarget ~ (Pronunciation * Morphology * Phonological Context * Target Voicing) * (ot1)+ot2+ot3+ (ot1+ot2+ot3 | item) + (ot1+ot2+ot3 | participant)*, where ot^x is orthogonal time raised to the power of 1, 2 or 3. The data is binomial, as at any given time-point the participant is either looking to the target image or not. The reference levels were Correct Pronunciation, Plural, Post-sonorant and Voiced. Note that the variables Phonological Context and Target Voicing were also used in Experiment 1 and assigned the same reference levels. In addition to the time-course information, the factors Pronunciation and Morphology have also been added to this model. Pairwise comparisons of the size of mispronunciation effect per word category were calculated using the function glht from the package multcomp (Hothorn, Bretz, & Westfall, 2008).

Results

Figure 3 shows the average target fixation to correct and mispronounced words. For clarity the data are split by voicing, morphology and phonological context.

Fig. 3a. *Experiment 2,time course of looking to correctly and mispronounced plural [t] words*

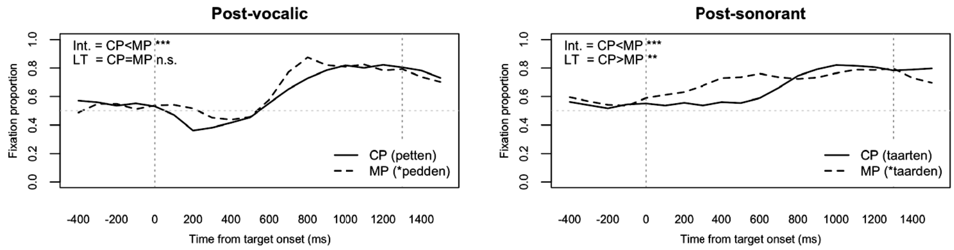

Fig. 3b. *Experiment 2, time course of looking to correctly and mispronounced plural [d] words*

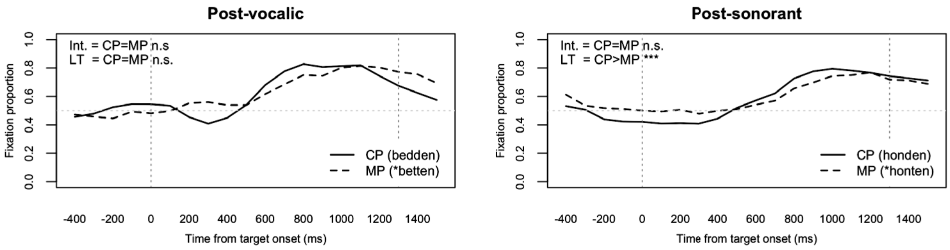

Fig. 3c. *Experiment 2, time course of looking to correctly and mispronounced monomorphemic [t] words*

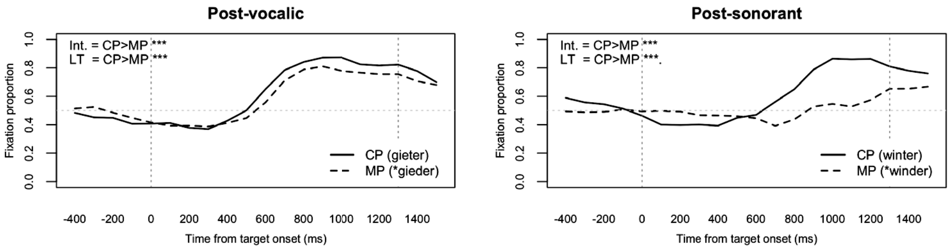

Fig. 3d. *Experiment 2, time course of looking to correctly and mispronounced monomorphemic [d] words*

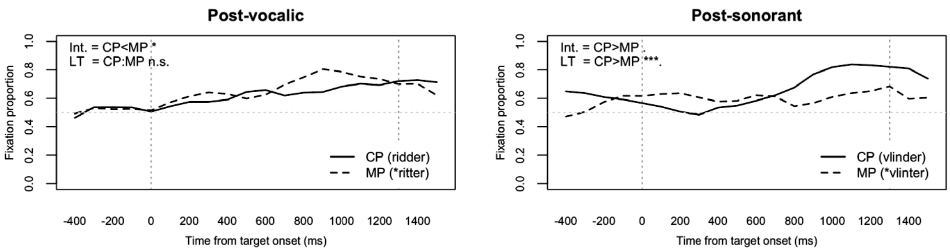

Figure 3 a-d. Target fixations to different trial types in Experiment 2. Solid lines correspond to gaze behaviour to correctly pronounced trials, and the dashed lines to mispronunciations. Looks above 50% indicate more looks to the target than distractor. The dotted horizontal line shows this chance level. Dotted vertical lines indicate the window of analysis, from target onset at 0 ms for a period of 1300 ms. Int. and LT indicate statistical differences between the two lines during the analysis window, corresponding to the pair-wise comparisons displayed in Table 8.

Full results and model estimates are presented in Table 9. The effect of Pronunciation is modified by Target Voicing, Morphology and Phonological Context. Of primary interest in this experiment is the effect that mispronunciations of voicing have on children's word recognition, measured in the amount of time overall they spend looking to the target image, and differences in the speed with which they identify the target. The intercept term reports the amount of time spent on the target, and the linear time term provides information about fixation speed. Sensitivity to mispronunciations is predicted to be evident in a lower intercept and lower linear time term for mispronunciations relative to correct pronunciations, that is, children look less to the target, and are slower to identify the target, if presented with a mispronunciation. Children displayed sensitivity to mispronunciation in either speed or overall looking times to plural words with /t/, either post-vocalic or post-sonorant, but not to plural words with /d/. They were sensitive to mispronunciations of three of the four monomorphemic word types, showing no sensitivity to mispronunciations of /d/ post-vocalically. We first report the effect of mispronunciations in each word type (Table 8), and then report how the size of the mispronunciation effect differed between words types (Table 9).

Children displayed sensitivity to mispronunciations on both the intercept and Linear Time term in three of the eight word-types; monomorphemic words with post-vocalic and post-sonorant /t/, and monomorphemic words with a post-sonorant /d/. When correctly pronounced, children spent more time looking at the target, and located it faster, than when it was mispronounced (Fig. 3c; monomorphemic, post-vocalic /t/: Intercept $\beta = -0.31$; $SE = 0.05$; $p < .001$; Linear Time: $\beta = -8.54$; $SE = 1.92$; $p < .001$; monomorphemic post-sonorant /t/: Intercept $\beta = -0.46$; $SE = 0.06$; $p < .001$; Linear Time $\beta = -31.97$; $SE = 2.08$; $p < .001$. Fig. 3d, right monomorphemic post-sonorant /d/; Intercept $\beta = -0.16$; $SE = 0.06$; $p = .07$; Linear Time $\beta = -21.39$; $SE = 2.18$; $p < .001$).

Mispronunciations of /d/ and /t/ post-sonorantally in plural words elicited a significant effect on the Linear Time term though not on the intercept term; children were faster to shift their gaze to the target when correctly pronounced. The intercept term was not significant for plural /d/ (Fig. 3b, right: Intercept $\beta = -0.01$; $SE = 0.05$; $p = 1.0$; Linear Time $\beta = -8.76$; $SE = 1.79$; $p < .001$). For plural /t/ words it was significant in the opposite direction to predicted; children spent longer looking to the target if it was mispronounced compared to when correctly pronounced (Fig. 3a right: Intercept $\beta = 0.29$; $SE = 0.05$; $p < .001$; Linear Time $\beta = -7.6$; $SE = 1.94$; $p = .002$;).

Mispronunciations of post-vocalic /t/ in plural words and post-vocalic /d/ in monomorphemic words also elicited greater looks to mispronunciations over correct pronunciations. In these conditions there was no difference in speed of recognition (Fig 3a and 3d, both left; post-vocalic plural /t/: Intercept $\beta = 0.23$; $SE = 0.06$; $p < .001$; Linear Time $\beta = -1.18$; $SE = 2.07$; $p = 1.0$; post-vocalic monomorphemic /d/: Intercept $\beta = 0.18$; $SE = 0.06$; $p = .03$; Linear Time $\beta = 5$; $SE = 2.06$; $p = .22$).

The final word type tested, plurals with a post-vocalic /d/, elicited no difference in children's looking behaviour. There was no difference in either the height or gradient of the curve, indicating that participants were not sensitive to mispronunciations of this type (Fig. 3b, left; Intercept $\beta = -0.04$; $SE = 0.05$; $p = 1.0$; Linear Time $\beta = -4.13$; $SE = 1.87$; $p = .35$).

Table 8

Pairwise comparisons of the effect of Mispronunciation on each of the word type.

Morph.	*Target Voicing*	*Phon. Context*		*CP Est.*	*MP Est.*	*Estimated dif. between CP and MP*	*Std. Error*	*z-value*	*p-value*
Plural	/t/	post-voc.	Int.	0.78	1.0	0.23	0.05	4.16	< .001 ***
			LT	16.45	15.28	-1.18	2.07	-0.57	1.0
		post-son.	Int.	0.61	0.89	0.29	0.05	5.4	< .001 ***
			LT	31.31	23.72	-7.6	1.94	-3.91	.002 **
	/d/	post-voc.	Int.	0.82	0.79	-0.04	0.05	-0.7	1.0
			LT	22.54	18.38	-4.13	1.87	-2.21	.35
		post-son.	Int.	0.46	0.45	-0.01	0.05	-0.19	1.0
			LT	28.63	19.88	-8.76	1.79	-4.9	< .001 ***
Mono.	/t/	post-voc.	Int.	0.81	0.5	-0.31	0.05	-5.98	< .001 ***
			LT	25.15	16.61	-8.54	1.92	-4.44	< .001 ***
		post-son.	Int.	0.6	0.14	-0.46	0.06	-8.28	< .001 ***
			LT	39.6	7.63	-31.97	2.08	-15.36	< .001 ***
	/d/	post-voc.	Int.	0.22	0.4	0.18	0.06	3.13	.03 *
			LT	26.86	31.85	5	2.06	2.42	.22
		post-son.	Int.	0.68	0.52	-0.16	0.06	-2.82	.07 .
			LT	29.09	7.7	-21.39	2.18	-9.83	< .001 ***

Note. Corrected *p*-values for all contrasts, including the reference plural, post-sonorant /d/.
Note. *** p < .001, ** p < .01, * p < .05, . p < .1

The differences between these pronunciation effects are apparent in the effects and interactions involving Pronunciation in the statistical model. There was a significant main effect of Pronunciation on the Linear Time term, indicating, as previously discussed, a less-steep increase in looks to target for mispronounced plural forms with a target /d/ in post-sonorant position, as opposed to correctly pronounced words (β = -8.76; *SE* = 1.79; $p < .001$). There was a significant interaction of Pronunciation * Morphology on both the intercept and linear time term (Pronunciation * Morphology: β = -0.16; *SE* = 0.08; $p < .05$. Pronunciation * Morphology * Linear Time: β = -12.63; *SE* = 2.81; $p < .001$), indicating that the effect of mispronunciation is greater, in both the height and gradient of the curve, for monomorphemic than plural words with /d/ in post-sonorant position. The interaction of Pronunciation * Voicing was significant on the intercept term (β = 0.3; *SE* = 0.07; $p < .001$), signifying that the effect mispronunciations have on the height of the curve was greater for plural words with post-sonorant /t/ than /d/.

Two three-way interactions involving the factor Pronunciation also reached significance on both the intercept and linear time terms. Firstly, the interaction of Pronunciation * Morphology * Voicing indicated that the difference in size of the mispronunciation effect between plural and monomorphemic forms when the target was post-sonorant, was further attenuated by voicing (Pronunciation * Morphology * Voicing: β= -0.59; SE= 0.11; p< .001. Pronunciation * Morphology * Voicing * Linear Time: β= -11.74; SE= 4.01; p< .01). The difference in magnitude of the mispronunciation effect between plural and monomorphemic words with post-sonorant /t/ was greater than the difference in the size of the mispronunciation effect between plural monomorphemic post-sonorant /d/ words, and this is true for both the height and steepness of the curve. The second three-way interaction at both the intercept and linear time term is Pronunciation * Morphology * Phonological Context (Pronunciation * Morphology * Phonological Context: β= 0.37; SE= 0.11; p< .001. Pronunciation * Morphology * Phonological Context * Linear Time: β= 21.76; SE= 3.96; p< .001). This interaction indicated that the effect of Pronunciation is attenuated by Morphology, but the magnitude of this effect is further attenuated by Phonological Context. For words with a post-sonorant /d/, the difference in the size of the mispronunciations effect between monomorphemic and plural words was greater than the difference in the size of the mispronunciation effect between post-vocalic monomorphemic and plural words with /d/. The three-way interaction of Pronunciation * Phonological Context * Voicing was not significant. Statistically speaking, the difference in the size of the mispronunciation effect between plural words with post-sonorant or post-vocalic /d/ is of the same magnitude as the difference between plural words with post-sonorant or post-vocalic /t/.

Table 9

Model output showing effects of Pronunciation, Morphology, Phonological Context and Voicing on children's looks to target in Experiment 2.

Effect	*Estimate*	*SE*	*z-value*	*p-value*
Intercept	0.46	0.2	2.28	.02 *
Pronunciation (CP vs. MP)	-0.01	0.05	-0.19	.85
Morphology (plural vs. monomorphemic)	0.22	0.24	0.91	.36
Phonological Context (post-sonorant vs. post-vocalic)	0.36	0.28	1.3	.19
Voicing ([d] vs. [t])	0.15	0.24	0.61	.54
Linear Time	28.63	5.28	5.42	< .001 ***
Quadratic Time	5.23	1.92	2.72	.0065 **
Cubic Time	-5.65	1.5	-3.77	< .001 ***
Pronunciation * Morphology	-0.16	0.08	-2.06	.039 *
Pronunciation * Phon.Context	-0.03	0.07	-0.38	.71
Morphology * Phon.Context	-0.82	0.35	-2.38	.02 *
Pronunciation * Voicing	0.3	0.07	4.41	< .001 ***
Morphology * Voicing	-0.23	0.35	-0.67	.5
Phon.Context * Voicing	-0.19	0.34	-0.57	.57
Pronunciation * Linear Time	-8.76	1.79	-4.9	< .001 ***
Morphology * Linear Time	0.45	5.75	0.08	.94
Condition * Linear Time	-6.12	6.47	-0.95	.34
Voicing * Linear Time	2.68	5.58	0.48	.63
Pronunciation * Morphology * Phon.Context	0.37	0.11	3.44	< .001 ***
Pronunciation * Morphology * Voicing	-0.59	0.11	-5.48	< .001 ***
Pronunciation * Phon.Context * Voicing	-0.03	0.1	-0.28	.78
Morphology * Phon.Context * Voicing	0.87	0.49	1.78	.07 .
Pronunciation * Morphology * Linear Time	-12.63	2.81	-4.5	< .001 ***
Pronunciation * Phon.Context * Linear Time	4.62	2.58	1.79	.07 .
Morphology * Phon.Context * Linear Time	3.89	8.09	0.48	.63
Pronunciation * Voicing * Linear Time	1.16	2.64	0.44	.66
Morphology * Voicing * Linear Time	7.83	8.13	0.96	.34
Phon.Context * Voicing * Linear Time	-8.74	7.93	-1.1	.27
Pronunciation * Morphology * Phon.Context * Voicing	-0.17	0.15	-1.08	.28
Pronunciation * Morphology * Phon.Context * Linear Time	21.76	3.96	5.5	< .001 ***
Pronunciation * Morphology * Voicing * Linear Time	-11.74	4.01	-2.93	.003 **
Pronunciation * Phon.Context * Voicing * Linear Time	1.8	3.84	0.47	.64
Morphology * Phon.Context * Voicing * Linear Time	-3.47	11.42	-0.3	.76
Pronunciation * Morphology * Phon.Context * Voicing * Linear Time	-4.75	5.66	-0.84	.4

Note. *** $p < .001$, ** $p < .01$, * $p < .05$, . $p < .1$

In summary, all factors included in our model, Morphology, Phonological Context and Voicing, influenced children's perception of mispronunciations in word-medial position. Mispronunciations were most disruptive to monomorphemic words with /t/, either in post-vocalic or post-sonorant position, that is, **gieder* and **winder* were not accepted by children as good representations of the target forms *gieter* and *winter.* Children were sensitive to mispronunciations of /d/ in monomorphemic words, albeit less so than they were to /t/. They showed a preference for mispronunciations of post-vocalic /d/ over correctly pronounced forms; **vlinter* was disruptive to word recognition, but **ritter* facilitated word recognition. Within plural words, children were not sensitive to mispronunciations of post-vocalic /d/; when presented with **betten* for *bedden* their ability to identify the target referent was not affected. Mispronunciations of /d/ following a sonorant were more noticeable and children were slower to fixate on the target if it is pronounced **honten* instead of *honden.* Of plural words with /t/, post-sonorantal mispronunciations hindered word recognition; children were slower and looked less to **tenden* than *tenten.* Mispronunciations of post-vocalic /t/ facilitated word-recognition; children spent significantly longer looking at the target image if it was presented as **pedden* instead of *petten.*

Discussion

The results from Experiment 2 confirmed that Dutch 3-year-olds are sensitive to mispronunciations of word-medial voicing. We found differences in the degree of sensitivity displayed, indicating that target voicing, morphological structure and phonological context all exert pressure on the robustness of children's phonetic representations. There was a crucial difference between children's sensitivity to mispronunciations of monomorphemic and plural forms, and children were sensitive to mispronunciations on monomorphemic words with little regard for target voicing or phonological context. That is, they noticed if /t/ was presented as [d], or /d/ was presented as [t]. There was some difference in their response to mispronunciations of monomorphemic forms with post-vocalic /d/, but we believe this can be attributed to lexical factors of the stimuli. The words in this condition were less frequent and less easy to depict than words in the other conditions and this likely impacted on recognition of these words when presented as either a correct or mispronunciation trial. The fact that they showed some sensitivity to mispronunciations in this condition allows us to conclude that despite issues with the items, children did recognise the pictures and mispronunciations of the target word, albeit less strongly than in the other monomorphemic conditions.

The symmetric pattern of sensitivity to voicing mispronunciations in monomorphemic forms contrasts with previously attested asymmetries in voicing detection in word-onset position by both Dutch toddlers (Van der Feest, 2007) and adults (Van Alphen & Smits, 2004). An account based on acoustic saliency or underspecification of the feature [voice] would predict that children notice mispronunciations of /t/ to [d] but not of /d/ to [t]. Underspecification of voicing would also not predict any differences based on context, and post-vocalic segments should behave in the same way as post-sonorant segments. In monomorphemic words children were sensitive to mispronunciations of voiceless segments in both contexts, which would be expected in this theory, but they were also sensitive to mispronunciations of voiced segments, albeit less strongly.

Symmetric and global sensitivity to mispronunciations in monomorphemic forms is crucial to our analysis of plural trials, as it proves that 3-year-olds have robust representations of voicing in word-medial position following either a vowel or sonorant. Deviances from this pattern in plural trials must be due to differences in morphological and not phonological structure. In plural forms the robustness and accuracy of children's voicing representations is sensitive to target voicing and phonological context, that is, children's representation of voicing in a potentially alternating context is affected by the surrounding context.

We predicted that children would have more robust representations of /t/ than /d/, as lexical items with /d/ undergo voicing alternations between the stem and plural form. Results from Experiment 2 confirmed this hypothesis. From the production data collected in Experiment 1 we know that children have difficulties with voicing alternations, preferring to use [t] throughout the paradigm whether this is accurate or not. The same pattern held in Experiment 2. Children were more sensitive to mispronunciations of /t/ than /d/ in a post-sonorant position, and the absence of a significant interaction of Pronunciation, Voicing and Phonological Context indicated that this also held post-vocalically.

We further predicted that children would be making use of phonological context, and would be more sensitive to mispronunciations of /d/ in a post-sonorant context than post-vocalically. This hypothesis is also upheld by our data, with a marginally significant interaction of Pronunciation and Context. The reverse of this hypothesis was that children would be more sensitive to mispronunciations of post-vocalic /t/ than post-sonorant /t/, however, we find little support for this prediction in our data. The non-significant interaction of Pronunciation, Voicing and Phonological Context indicates that the effect for /t/ plurals is similar to the effect for /d/ plurals. Looking at the pair-wise comparisons reveals that the effect of a mispronunciation on children's gaze behaviour is greater for post-sonorant /t/ plurals than post-vocalic. The effect of phonological context is further supported by the significant interaction of Pronunciation, Morphology and Voice which indicates that the difference in magnitude of the mispronunciation effect for monomorphemic and plural words with post-sonorant /t/ is smaller than for post-sonorant /d/; for words with a post-sonorant /t/ morphological context has less effect on children's representations than it does for words with a post-sonorant /d/.

Taken together, we interpret our results as indicating that children have robust representations of word-medial voicing in monomorphemic words. Their across-the-board sensitivity approaches ceiling and therefore does not allow us to draw conclusions about the role of phonological context in monomorphemic forms. Robustness, or accuracy, of voicing representations in plural forms is affected by target voicing, that is, whether a form contains an alternation or not, and phonological context. Children notice mispronunciations of /t/ more than /d/; they notice when an alternation is erroneously added to a paradigm more than when it is excluded. When /d/ follows a vowel they accept correct pronunciations and mispronunciations equally, putatively indicating an awareness that alternations may occur within an inflectional paradigm although they are not certain which paradigms this may be. They use input phonotactic frequency to specify which lexical items contain an alternation; when /d/ is preceded by a sonorant, they are less accepting of mispronunciations, indicating a more accurate representation of alternations in these words.

General Discussion

Experiments 1 and 2 demonstrated that phonotactic probabilities influence Dutch toddlers' lexical representations of morphophonological alternations. Ernestus and Baayen (2003) found that the underlying status of a stem-final obstruent was more predictable than had previously believed, and naïve adults were able to make use of this predictability. Our data show that the underlying status of a stem-final obstruent is also predictable from child-directed speech, and 3-year-olds are able to "predict the unpredictable" (Ernestus & Baayen, 2003).

Experiment 1 looked at children's productions of voicing alternations in familiar plural words. Our results are consistent with previous literature (Kager, 1999; Kerkhoff & De Bree, 2005; Kerkhoff, 2007; Van Wijk, 2007; Zamuner et al., 2011) in showing that toddlers have difficulties with voicing alternations and a strong tendency to adhere to a principle of Paradigm Uniformity (Steriade, 2000). That is, they avoid voicing alternations between the stem and plural form, and produce [t] more often than [d] regardless of whether this is accurate or not. Despite this preference, if the stem-final obstruent is preceded by a sonorant rather than a vowel, toddlers are more likely to produce an alternation. Alternations are more frequent in a post-sonorant context and, in line with our prediction, toddlers make use of this phonotactic cue. Results from Experiment 1 can be summarised in a hierarchy of production accuracy; VT > NT > ND > VD.

In Experiment 2 we were interested in whether children's production abilities provide a reliable reflection of their lexical knowledge. Using the Preferential Looking Paradigm, which does not require an overt response from the child, we tested their sensitivity to voicing mispronunciations in plural forms. Again it is possible to summarise our results hierarchically, this time from the most to the least sensitivity to mispronunciations; NT > ND > VT > VD. Whereas in Experiment 1 the divide was by voicing, here it is by context. We further tested sensitivity to mispronunciations of voicing word-medially in monomorphemic words and found no evidence of differential sensitivity depending on underlying voicing or phonological context. The difference between sensitivity to mispronunciations in monomorphemic and plural words challenges the view that morphologically complex words are represented as non-decomposable units in the lexicon, as children were sensitive to the morphological complexity of plural forms. Results from plural forms highlight the role of phonotactic probability in children's representations of voicing alternations; children were more sensitive to mispronunciations in a post-sonorant context than post-vocalic context.

Although the exact pattern of results in Experiments 1 and 2 differs, both experiments show a clear impact of phonological context on children's performance. This is a factor that evidently plays a role in Dutch-learning children's representations of voicing alternations. They have a more robust, or accurate, representation of underlying voicing in lexical items where a sonorant precedes the stem-final voiceless obstruent than a vowel does. This follows the distributional pattern attested in both child- and adult-directed speech, indicating that children are influenced by the frequency of phonological sequences in their input. Children are not paying attention to individual segments alone, but are making use of sequential patterns in words or syllables. The influence that phonological context has on the acquisition of voicing alternations is not predicted by theories of acquisition of morphophonological alternations (Hayes, 1999; Peperkamp & Dupoux, 2002; Tesar & Prince, 2003). These theories predict that acquisition of voicing alternations will be slow and demanding, as the learner can only specify which morphological paradigms contain an alternation once they have the morphological and semantic knowledge to generalise over lexical items. Smaller units, such as phonotactic patterns are not taken into consideration. The process of acquiring morphological acquisition has previously been described as so difficult for children that it will not be fully acquired until adolescence (Pierrehumbert, 2003). Our data show that children are using bottom-up knowledge, in the form of the word-shape, to help them predict which morphological paradigms contain a voicing alternation. Including bottom-up processing makes the pattern of alternations more predictable, and therefore less complex than has previously being assumed.

There is a long line of research demonstrating that infants and children are sensitive to phonotactic probabilities of their ambient language (Coady & Aslin, 2004; Frisch et al., 2000; Hollich et al., 2002; Jusczyk et al., 1993, 1994; Mattys et al., 1999; Mattys & Jusczyk, 2001; Munson, 2001; Storkel & Rogers, 2000; Storkel, 2001; Treiman et al., 2000; Vitevitch et al., 1997; Zamuner et al., 2004). In this light our results are unsurprising; why wouldn't children use phonological context and input frequency to help them learn about alternations? In addition, Seidl et al. (2009) and White et al. (2008) have shown that infants can use allophonic variation to learn alternating patterns. Voicing alternations are not allophonic in Dutch, alternations do not occur in complementary distribution, making it more difficult to form generalizations, but our data show that children are sensitive to distributional patterns.

A question raised by our data concerns what the nature of the unit is that children are using, if not individual segments. The assumption made in this paper has been something akin to the biphone frequency of nasals and obstruents. This is not undisputed. For example, Vihman and Croft (2007) would argue that it is the whole word that is influencing children's representations of alternations, arguing that children's lexical representations contain templates of whole word forms. Others would argue for the role of the syllable (De Cara & Goswami, 2002; Goswami & Bryant, 1990; Kessler & Treiman, 1997; Treiman, 1988). In particular the role of the onset-rime structure of the syllable has been identified as important to young children. For example, Goswami and Bryant (1990) found that pre-lexical children performed better in onset-rhyme tasks (for example segmenting the word *cat* into /k/-/æt/), than phoneme identification tasks (*cat* is /k/-/æ/-/t/). They further argue that success in phoneme awareness tasks improves greatly with literacy (cf. work on phoneme awareness in illiterate adults Morais, Cary, Alegria, & Bertelson, 1979). De Cara and Goswami (2002) show that children's rime awareness is linked to the density of rime neighbours in the early lexicon (e.g. *hat* and *cat*). The link between subsyllabic structure and frequency can be related directly to our data and literature on phonological neighbourhoods (cf. Luce & Pisoni, 1998). Phonological neighbourhood effects in the developing mental lexicon are well attested (e.g. Mani & Plunkett, 2011; Newman, Samuelson, & Gupta, 2008; Zamuner, 2009). Our data further demonstrate that the child's mental lexicon is organised by phonological similarity. The high frequency of alternations following sonorant obstruents gives rise to a denser phonological neighbourhood, strengthening children's representation of this pattern. A resulting prediction is that children would also generalise this pattern to newly learned or novel word forms. In Experiment 1 we found some evidence for overgeneralisation of voicing in post-sonorant /t/ words, where children made more voicing errors (**tenden*) than in the post-vocalic context (**fluiden*).

An alternative explanation for the advantage of alternations in post-sonorant context could be linked to the notions of naturalness and markedness. Natural phonology argues that phonology is phonetically grounded, proposing a functional explanation for sounds or sound sequences embedded in ease of articulation and perception (Dressler, 1984; Westbury & Keating, 1986). According to this theory, voiceless segments in final position are natural, as are voiced segments following a nasal. Evidence comes from articulatory and perceptual accounts (Hayes & Stivers, 1995; Solé, 2007), as well as typological prevalence (Locke, 1983; Pater, 1999) and ease of acquisition (B. L. Smith, 1979; N. V. Smith, 1973). Post-nasal voicing is of particular relevance to our data. If this sequence is more natural, it is likely that children will perceive it better and be able to produce it earlier. It could also explain children's over-use of voicing in post-sonorant /t/ words in Experiment 1. However, it is difficult to tease apart explanations of naturalness or frequency because natural phonology assumes that more natural sequences or processes will also be more frequent in a language. We cannot conclude whether children's representations of voicing alternations in post-sonorant position are more robust because they are more natural (and therefore more frequent and easier to perceive, articulate and learn), or only because they are more frequent.

Another issue that arises from our data is the difference between Experiments 1 and 2. In both experiments children show sensitivity to phonological context, but their perceptual representations (Experiment 2) appear to be more robust than their productive abilities. In Experiment 2 children displayed sensitivity to mispronunciations of /t/ and /d/ in post-sonorant position. In Experiment 1, despite being more accurate in producing [d] in a post-sonorant context, participants still made many errors in this context. That is, their perceptual abilities are more advanced of their productive abilities. It has long been acknowledged that children's perceptive or comprehension abilities precede production abilities, in many aspects of language acquisition (e.g. Clark & Hecht, 1983; Petretic & Tweney, 1977; Shipley, Smith, & Gleitman, 1969). For example, English-learning infants comprehend all plural allomorphs ([s], [z], and [ɪz]) by 36 months old (Kouider et al., 2006), but five-year-olds still have difficulty using the syllabic form [ɪz] (Berko, 1958). Similarly, Gerken, Landau and Remez (1990) found that although younger children tend to omit function morphemes from their own speech, they do comprehend them.

The question of why this asymmetry exists has also been widely discussed, and there are two primary arguments used to explain why children's speech production may lag behind comprehension. The first group of theories assume that children's lexical representations are immature, and this will have an impact on both their production and perception (e.g. Ferguson & Farwell, 1975; Fikkert, 2010; Vihman & Croft, 2007). These accounts explain the symmetry of developmental patterns in production and perception, but not the existence of a time-delay between the two. Considering only our production data, one could conclude that children's representations of lexical items are not adult-like, and do not specify whether a stem-final obstruent is voiced or not; plurals are produced by suffixing *–en* to the stem. However, this explanation does not fit with the results of Experiment 2; apparently children's lexical representations of stem-final, post-sonorant obstruents *are* specified for voicing, as they notice if they are presented with a mispronunciation. The alternative theoretical approach assumes that children's lexical representations are have adult-like, and inaccurate productions arise through articulatory limitations or difficulties in mapping representations to articulatory gestures (e.g. Inkelas & Rose, 2007; MacNeilage & Davis, 2000; Pierrehumbert, 2003). A purely articulatory account of children's inaccuracy in Experiment 1 is unlikely, as previous literature has shown that children of this age can produce a voicing contrast in word-medial position (Zamuner et al., 2011). In addition, children's lexical representations, as demonstrated in Experiment 2, are not entirely adult like. Children were sensitive to mispronunciations of /d/ in a post-sonorant context, but not post-vocalically.

The asymmetry of production and perceptual abilities thus speaks against claims that children's lexical representations are immature (e.g. Ferguson & Farwell, 1975; Fikkert, 2010; Vihman & Croft, 2007), and supports a claim that the child's lexicon is specified in detail, but there are limitations on production, for example in articulatory control or mapping representations to articulatory gestures (e.g. Inkelas & Rose, 2007; MacNeilage & Davis, 2000; Pierrehumbert, 2003).

However, production data indicates that 3-year-olds can produce a voicing contrast in this position. Looking beyond the child-language literature, psycholinguistic models of speech production have included a perceptual loop, a self-monitoring system that allows the speaker to analyse the accuracy of their speech using the same mechanism as used in comprehension. That is, speakers analyse their own inner speech using the same comprehension processes as they use when listening to somebody else talk. If this is the case, the asymmetry attested is difficult to account for - if children notice mispronunciations in the speech of others, why do they persistently make errors in their own speech? A more recent paper by Huettig and Hartsuiker (2010) proposes a solution to this conundrum. They found that speakers looked to phonologically related neighbours in an array only after they had produced the target word, and not during production. They take this as evidence that speakers do monitor their speech using perceptual processes, but they monitor external and not internal speech, i.e. they monitor speech after they have produced it and not before. Assuming that children do not monitor their inner speech can account for their inaccurate production, despite noticing inaccuracies in external speech. However, whereas an adult would be expected to repair a speech error, children do not. It remains an open question as to whether children monitor their speech at all, or do so but do not see repairs as necessary.

Our data speak in favour of an approach that allows for some developmental restructuring of the mental lexicon, but also for an asymmetry between production and perception abilities during the acquisition phase. The acquisition theories of Peperkamp and Dupoux (2002) and Tesar and Prince (2004) do not discuss differences between production and perception, but they do allow for lexical reorganisation. They propose that infants use phonotactic distributions to infer that there is no voicing contrast in final position, and in the absence of any other evidence they will establish a lexical representation identical to the surface form. Once they are able to draw comparisons across morphological variants of the same lexical item they will notice which paradigms contain a voicing alternation and alter their representations if necessary. It seems that Dutch 3-year-olds are in the middle of restructuring their representations, and are using phonological context to help them. Their representations of words with a post-sonorant stem-final obstruent are more developed than their representations of post-vocalic stem-final obstruents.

The difference in results between Experiments 1 and 2 could also arise through different task requirements if it is assumed that in Experiment 1 children had to make a decision between [t] or [d], whereas in Experiment 2 they had to decide whether they found [t] or [d] more acceptable. Experiment 2 thus allowed for more gradient behaviour; which version is more or less acceptable. This explanation of the task demands of Experiment 1 is not entirely correct; children did not participate in a forced choice task, but a production task. As such, our manner of coding responses into a binary distinction may have misrepresented the complexity of children's productions. All responses were coded by adult listeners as either [t] or [d], and we removed tokens where all three coders did not agree. Speech, and the difference between two categories is gradient, though perception is categorical. It is not impossible that the children in our study were attempting to make a contrast between [t] and [d], but it fell within a single category of adult perception. Evidence for so-called covert contrasts have previously been found for the voicing contrast in English-learning children (Macken & Barton, 1980; Maxwell & Weismer, 1982). This is even more likely in the situation here, if, as we have suggested, children's lexical representations are also in transition from a form with /t/ to a form with /d/ (Hewlett & Waters, 2004). This change will not happen immediately and in one go, therefore increasing the chance of gradient productions during this period of change.

In conclusion, Dutch three-year-olds know more than they can say about voicing alternations. Production data alone suggests that their representations of stem-final obstruents are non-specific, and, without this specificity they are forced to rely on paradigm uniformity and similarity to other forms in their input. Results from Experiment 2, however, indicate that production data underestimates children's abilities. In particular they are sensitive to the high frequency of voicing alternations after sonorant consonants. It has previously been proposed that learnability of morphophonological alternations is dependent on frequency (Zamuner et al., 2011), and alternations in Dutch are difficult to acquire because they do not occur very often. Cross-linguistic comparisons can be drawn, for example to European Portuguese, where morphophonological alternations have a higher frequency and are accordingly acquired earlier (Fikkert & Freitas, 2006). Our data indicate that it is not only frequency of the alternation that is important, but frequency of the alternation embedded in a given context. Dutch children's lexical representations initially contain the neutralised form, but by three years old they are starting to restructure their lexicon to include links between word forms with both a neutralised and non-neutralised obstruent. This process is far from complete at this age, however, we have shown that this knowledge emerges younger than previously attested (Kerkhoff, 2007) if phonotactic probability is taken into consideration and more sensitive tasks are used.

Appendix I

Experiment 1 results - production accuracy by item.

Word type	*Item*	*No. Tokens*	*No. Accurate tokens*	*Accuracy (%)*
Post-vocalic [t]	botten	20	20	100
	fluiten	22	21	95.5
	noten	18	17	94.4
	petten	26	25	96.2
Post-vocalic [d]	bedden	20	6	30
	broden	18	3	16.7
	hoeden	27	5	18.5
	kleden	12	4	33.3
Post-sonorant [t]	kaarten	13	11	84.6
	olifanten	12	8	66.7
	taarten	24	20	83.3
	tenten	24	21	87.5
Post-sonorant [d]	eenden	19	11	57.9
	manden	10	1	10
	paarden	20	8	40
	zwaarden	8	2	25

Appendix II

Acoustic characteristics of stimuli in experiment 2.

Word-type	*Item*	*Correct Pronunciation*		*Mispronunciation*	
		Duration (ms)	*Pitch (Hz)*	*Duration (ms)*	*Pitch (Hz)*
Post-vocalic [t]	botten	488	212	451	200
	fluiten	688	214	637	206
	noten	612	218	639	211
	petten	452	197	430	202
	boter	562	172	556	197
	gieter	674	207	562	205
	ketting	510	197	459	197
	sleutel	692	210	663	188
Post-vocalic [d]	bedden	447	201	478	209
	broden	613	202	665	206
	hoeden	434	197	440	207
	kleden	606	205	674	185
	ladder	550	220	498	217
	pudding	482	200	469	203
	ridder	476	211	631	215
	schaduw	650	192	731	189
Post-Sonorant [t]	kaarten	700	212	737	183
	olifanten	1043	168	1136	164
	taarten	727	179	738	178
	tenten	736	180	668	184
	groente	668	201	665	189
	skelter	823	182	800	187
	winter	634	184	647	189
	wortel	643	171	734	177
Post-Sonorant [d]	eenden	710	174	782	177
	manden	828	177	807	181
	paarden	714	195	786	186
	zwaarden	783	206	861	197
	aarde	574	195	615	182
	panda	555	173	573	166
	vlinder	645	184	715	183
	zolder	640	184	730	176

Appendix III

Number of trials remaining in the analysis of Experiment 2 by item.
In the post-vocalic condition the maximum possible is 37, and post-sonorant is 35, corresponding to the number of participants included the analysis.

Condition	*Word type*	*Target*	*No. of trials remaining*
Post-vocalic	Plural [t]	botten	26
		fluiten	28
		noten	24
		petten	29
	Plural [d]	bedden	33
		broden	33
		hoeden	37
		kleden	28
	Monomorphemic [t]	boter	31
		gieter	31
		ketting	33
		sleutel	36
	Monomorphemic [d]	ladder	32
		pudding	27
		ridder	17
		schaduw	26
Post-sonorant	Plural [t]	kaarten	23
		olifanten	31
		taarten	31
		tenten	33
	Plural [d]	eenden	33
		manden	35
		paarden	34
		zwaarden	27
	Monomorphemic [t]	groente	26
		skelter	24
		winter	23
		wortel	29
	Monomorphemic [d]	aarde	15
		panda	31
		vlinder	33
		zolder	18

5

Summary & Conclusions

The research reported in this thesis has addressed the previously unexplored topic of how morphophonological alternations, such as those caused by the interaction of obligatory devoicing with inflectional structure of nouns and verbs, are acquired in the first years of life. Three general conclusions may be extracted from the experimental findings: (1) the native language plays an important role, (2) children make use of phonotactic probabilities and (3) perception precedes production. In the context of the acquisition of morphophonological alternations, each of these findings adds new knowledge to our understanding of language acquisition. In the context of language acquisition research in general, each further strengthens similar conclusions drawn from studies on the acquisition of other aspects of linguistic structure.

1. Native language plays an important role in the acquisition of morphophonological alternations

Cross-linguistic differences in the acquisition of morphophonological alternations were investigated in Chapters 2 and 3. Chapter 2 used the Headturn Preference Procedure (HTPP) to investigate whether Dutch and German 9-month-olds displayed sensitivity to the statistical properties of inflectional affixation in their native language and the associated presence of voicing alternations. Infants were familiarised on passages containing monosyllabic, obstruent-final nonsense nouns, and tested on lists of bisyllabic, plural forms of the familiarised words. In the first condition the plural was formed by suffixation alone, in the second a voicing alternation also occurred. German infants recognised the familiarised words in the suffixation only condition, but not in the alternating condition. Dutch infants did not display a preference in either condition. It was concluded that German 9-month-olds are able to use the prosodic and inflectional morphological properties of their language to assist their early segmentation abilities, although they treat [t] and [d] as contrastive phonemes. At the same age Dutch infants are not yet sensitive to the relationship between members of an inflectional paradigm.

Chapter 3 also directly compared Dutch and German learners, but at the older age of three years. In this study the Preferential Looking Paradigm was used to investigate whether children's lexical representations of obstruent-final stem forms were specified for voicing alternations. Sensitivity to mispronunciations of voicing in word-medial position was measured, contrasting plural forms where the crucial obstruent was in a potentially alternating position with monomorphemic forms that never alternate. Both Dutch and German learners were sensitive to mispronunciations in monomorphemic forms, indicating that they do have specified representations for voicing in word-medial position. Dutch children displayed an asymmetric sensitivity to mispronunciations of voicing in plural words; they noticed mispronunciations of /t/ to [d] but not vice versa. German children, on the other hand, were sensitive to mispronunciations in both directions. Again, this result was interpreted as evidence that German-learners knowledge of morphology and voicing alternations is further developed than that of their age-matched Dutch peers.

Results from Chapters 2 and 3 support evidence that infants rapidly tune in to properties of their native language (cf. Cutler, 2012 for overview of literature). The differences established indicate that early sensitivity to inflectional morphology develops earlier in German than Dutch, presumably due to the higher frequency of, and greater variability in, the inflectional system of German. It is unlikely that infants of this age have knowledge of inflectional morphology per se, but rather that they are sensitive to prosodic properties of native language stress patterns and reduction processes. At three years old German children's knowledge of voicing alternations is beyond that of Dutch 3-year-olds. In addition to differences in the inflectional system it is likely that the functional load of the voicing contrast and the higher frequency of voicing alternations are influential in children's ability to learn about alternations in the morphological paradigm.

2. Children make use of phonotactic probabilities when acquiring morphophonological alternations

Despite the finding that Dutch-learners lag behind German-learners, experiments from Chapter 4 indicated that Dutch children are not completely insensitive to voicing alternations, and do possess accurate lexical representations. A confounding factor in Chapter 3 was different stimuli types between the languages. Because it was not possible to find enough target items with intervocalic coronal stops in German a number of items were included where the target obstruent followed a sonorant obstruent (liquid or nasal). Informal analyses indicated that these different contexts might have influenced the data. This observation was followed up systematically in Chapter 4 with Dutch 3-year-olds.

Voicing alternations occur more frequently in Dutch in a post-sonorant context. This is true for both adult- and child-directed speech, and adults have previously been shown to make use of this distribution when predicting whether an alternation occurs or not (Ernestus & Baayen, 2003; Sebregts & Strycharczuk, 2012). Accordingly, it was hypothesised that Dutch children would make use of the distribution of voicing alternations in their lexical representations of voicing alternations, a hypothesis that was supported by both production and perception data. Children produced voicing alternations more accurately in a post-sonorant context, and in a mispronunciation detection task they were more sensitive to mispronunciations of /d/ post-sonorantally than post-vocalically. This result is in line with previous research indicating that infants and children make use of phonotactic probabilities in various aspects of language acquisition (Coady & Aslin, 2004; Frisch, Large, & Pisoni, 2000; Hollich, Jusczyk, & Luce, 2002; Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993; Jusczyk, Luce, & Charles-Luce, 1994; Mattys, Jusczyk, Luce, & Morgan, 1999; Mattys & Jusczyk, 2001; Munson, 2001; Storkel & Rogers, 2000; Storkel, 2001; Treiman, Kessler, Knewasser, Tincoff, & Bowman, 2000; Vitevitch & Luce, 1999; Zamuner, Gerken, & Hammond, 2004).

The principle underlying this effect is presumed to be the same as that underlying the cross-linguistic difference at this age. It was argued that German children's robust knowledge of voicing alternations stems from a combination of factors that make voicing alternations easier to acquire, including frequency, the functional load of the voicing contrast and ease of articulation. Frequency and ease of acquisition play a role in the post sonorant context in Dutch; voiced obstruents are more frequent following a sonorant, particularly a nasal, and voicing is more natural in this position (cf. Dressler, 1984; Westbury & Keating, 1986). As a result, the alternation is easier to acquire in this context.

3. Perception precedes production in the acquisition of morphophonological alternations

Chapter 4 also addressed the relationship between production and perception of voicing alternations, concluding that children's productions of voicing alternations do not provide a valid reflection of their knowledge. Although not addressed directly for German children in this thesis, on the basis of previous studies (Van de Vijver & Baer-Henney, 2011) and the results of Chapter 3 it can be assumed that this conclusion is also relevant for German-learners. It has long been recognised that children's perceptual, or comprehension, abilities are advanced of their productive knowledge (cf. Clark & Hecht, 1983; Petretic & Tweney, 1977; Shipley, Smith, & Gleitman, 1969), but previous research into the acquisition of voicing alternations has nevertheless focussed on children's production accuracy (cf. Kerkhoff & De Bree, 2005; Kerkhoff, 2007; Van de Vijver & Baer-Henney, 2011; Van Wijk, 2007; Zamuner, Kerkhoff, & Fikkert, 2011, but see also Zamuner, Kerkhoff, & Fikkert, 2006) with perceptual knowledge and the relationship between the two domains remaining under studied.

A methodological point is also highlighted here as the data support the claim that a comprehensive model of language acquisition can only be obtained by undertaking multi-faceted studies including different modalities, domains, languages and experimental methods. Looking only at production data has previously led to the conclusion that non-allophonic morphophonological alternations are so complex that they will not be acquired until adolescence (Pierrehumbert, 2003). This conclusion is not disputed, as children do make many errors when producing voicing alternations, and they require special attention during school literacy training (Neijt & Schreuder, 2007). However, production data underestimates children's knowledge. Kooijman, Johnson and Cutler (2008) made a similar call for more integrated studies using different measures. They highlighted differences between electrophysical and behavioural measures, arguing that brain responses form a precursor to overt behaviour. This thesis has similarly demonstrated the need for more structured study into the differences in performance apparent in more or less demanding tasks.

4. Towards a theory of the acquisition of morphophonological alternations

Studies presented in this thesis provide snap-shots of children's knowledge about voicing alternations at two points of development. In this section the links between the two ages will be discussed, in an attempt to map the course of development of morphophonological alternations. Of course, if the acquisition of morphophonological alternations is seen as a puzzle, it is not a child's puzzle with only these two pieces. Many more pieces need to be identified and put in their place in order to arrive at a comprehensive model, including collecting experimental data from children in the intervening age period. Gaps in knowledge will also be discussed here, with some suggestions for experiments that would provide the necessary supplementary data. An overview of the proposed developmental course is presented in Figure 1.

Chapter 2 provides more evidence pertaining to the remarkable statistical abilities of infants, particularly during their first year. German 9-month-olds are able to use the distributional properties to ascertain that morphologically related word-forms are not different lexical items, but share some commonality beyond phonological form overlap. French 11-month-olds also display similar abilities (Marquis & Shi, 2012). Relating to phonology of voicing, during this first year infants determine which acoustic contrasts are linguistically relevant, and their ability to discriminate irrelevant contrasts decreases (Werker & Tees, 1984). If infants are aware of the voicing contrast, it is unclear when they become aware that voicing is not contrastive in final position. Hayes (1999), Peperkamp and Dupoux (2002) and Tesar and Prince (2003) proposed that phonotactic learning occurs early, and infants use their knowledge of the lack of voicing contrast to learn about voicing alternations. This seems a plausible approach, but it has not been empirically tested. The German-learning infants who participated in Chapter

2 were sensitive to the relevant difference between [t] and [d], but we do not know the extent of their knowledge or sensitivity to word-final voicing. Even if they had succeeded in the alternating condition, it would have shown that they are aware of the similarity between [t] and [d], and suggested an awareness of a functional link, but not provided direct evidence for knowledge of voicing neutralisation.

In an experiment with Dutch infants Zamuner (2006) found that 10-month-olds were unable to discriminate voicing or place of articulation features in word-final position, although they could do in word-initial position. At 16 months old infants were able to discriminate place of articulation features word finally, but not voicing. If infants were not sensitive to voicing contrasts in final position they may still have been able to succeed in the alternating condition of Chapter 2 by focussing on the similarities between the whole word-forms and the shared place and manner features of [t] and [d]. Zamuner (2006) tested Dutch-learning infants, and it is possible that German infants would be more sensitive to changes in voicing in word-final position than Dutch infants due to the previously highlighted cross-linguistic differences. If this were the case German infants may be able to establish intraparadigmatic links involving voicing alternations more readily.

Further research is needed in order to establish when infants become aware of neutralising phonotactic constraints. Once this point has been established it can further be investigated how infants utilise this information. This research must, in addition, take language-specific differences in the complexity and variation within the phonological, morphological and lexical systems into consideration. German learners are ahead of Dutch learners in acquiring the voicing contrast in production (Kager, Van der Feest, Fikkert, Kerkhoff, & Zamuner, 2007), though the impact of this difference in perception or lexical representations has not been exhaustively studied. Voicing is only one feature of the phonological system, and the cross-linguistic asymmetry attested in this thesis manifests itself differently for the acquisition of other feature contrasts in the same two languages. Altvater-Mackensen (2010) showed that Dutch infants are ahead of their German peers in the acquisition of manner features. She argued that this is attributable to the greater complexity of the system of manner features in German, which includes stops, fricatives and affricates, whereas Dutch has only stops and fricatives.

There are also some more specific follow-up experiments to those presented in Chapter 2 that could be conducted. For example, it was concluded that German infants had reached a further stage of development of inflectional morphology than Dutch infants. This conclusion gives rise to a prediction that can readily be tested; do older Dutch infants (e.g. 12-month-olds) succeed in the non-alternating condition? It was further assumed that German infants have both the morphological and phonological knowledge necessary to succeed in the alternating condition, and the next stage for them is to combine these two skills or knowledge sets. Again, this predicts that older infants would succeed where younger infants failed, and replicating this task with older German infants would allow for this prediction to be tested. The knowledge of 9-month-olds could also be further probed using a different experimental paradigm. Previous studies have identified electrophysical measures as a way to elicit responses from infants prior to them being visible in behavioural measures (Kooijman et al., 2008). This approach could be used, for example, to test whether Dutch infants already have some knowledge of properties of inflectional morphology, the effects of which are not yet strong enough to be elicited in a behavioural paradigm.

The relationship between phonotactic probabilities and voicing neutralisation is also an avenue that warrants further investigation. Chapter 4 established that Dutch three year olds' lexical representations are more robust in words where the likelihood of an alternation is high, in this case following a sonorant. Informal analyses of data from Chapter 3 also suggested that this plays a role in German too. Sensitivity to phonotactic probabilities has been shown as one of the statistical properties that young infants are sensitive to (Mattys et al., 1999; Mattys & Jusczyk, 2001). The open question is whether infants can exploit this cue in helping them to establish that there is a phonotactic constraint against voicing in final position.

The results of Chapter 2 indicate that German provides infants with an early advantage in acquiring (precursors to) inflectional morphology and the voicing contrast. Chapter 3 showed that German children have an advantage over their Dutch peers in the lexical specification of voicing alternations at 3 years old. The knowledge being tapped into in each of these chapters is very different and it is not apparent whether there is a direct link between the two; do German toddlers have a lexical advantage as young children because of an early advantage in their ability to exploit statistical cues? Another way of asking this question is; to what extent are infants' abilities in extracting statistical or distributional patterns from the input linguistic or pre-linguistic? The words "precursors to" were cautiously included in parentheses above to reflect this uncertainty. It is well established that infants can extract many statistical regularities from their speech input (Saffran, Aslin, & Newport, 1996). In addition, a recent body of research has focussed on how individual differences in early language skills such as statistical learning or segmentation impact on later language development. The consensus is that there is a positive correlation between the two; infants who show advanced abilities in extracting regularities from the speech stream have increased linguistic abilities in (early)childhood (Junge, Kooijman, Hagoort, & Cutler, 2012; Kooijman, Junge, Johnson, Hagoort, & Cutler, 2013; Newman, Ratner, Jusczyk, Jusczyk, & Dow, 2006; Singh, Reznick, & Xuehua, 2012; Tsao, Liu, & Kuhl, 2004) indicating continuity between stages of development. Early skills clearly act as a foundation for later linguistic development, but what is the locus of continuity? Studies also show that infants are proficient in extracting patterns from tonal or visual sequences (Saffran et al., 1996). It could be that infants with better domain-general pattern-recognition or memory skills can apply these to speech perception, providing them with a head-start in language processing, the effects of which last into childhood (cf. Shafto, Conway, Field, & Houston, 2012). A second issue concerns the nature of the representations that infants build in the early stages, and their function in later language acquisition. On the one hand, infants could build representations that childhood representations build directly on to. On the other hand, the purpose of the first year may not be to build representations, but to develop highly specialised, efficient strategies for processing the native language and true linguistic acquisition occurs later (Cristia & Seidl, 2011). In terms of the studies presented here, it is not clear whether the early ability that German 9-month-olds have in identifying morphologically related words feeds directly into early lexical representations or not. Further studies into the nature of early representations including longitudinal data is required to establish whether German 9-month-olds in Chapter 2 exhibited precursors to morphological knowledge or the beginnings of a morphological system, and how this system develops between this age and 3-years-old.

Between nine months and three years old children acquire and develop a multitude of skills in a number of domains. Linguistically the lexicon increases dramatically in size, alongside semantic word-meaning mappings, and the ability to produce complex utterances. Learners of both Dutch and German will, during this period, acquire the voicing contrast and start using and comprehending markers of inflectional morphology. The course of acquisition of morphology also requires discussion. Data in Chapters 3 and 4 support a dual-route model of access to complex words similar to that proposed by Baayen, McQueen, Dijkstra and Schreuder (2003). Contrasting to stronger versions of a dual-route hypothesis (Clahsen, 1999; Marcus, 1995; Marcus et al., 1992; Pinker, 1998) this model assumes that speakers make use of both full-form storage and decompositional parsing mechanisms when processing morphologically complex words, but crucially, the division of labour is not by regularity but by properties such as frequency or the degree of overlap between the stem and inflected form. In this interpretation there is greater chance that forms with less overlap between the stem and inflected form will be accessed via their whole form rather than decomposed, but similarly, high frequency transparent forms may also be accessed via the same route. Morphological paradigms containing a voicing alternation overlap less than forms with no alternation. Note however that even with no alternations in the paradigm there is not complete overlap of forms because of differences in syllabification or vowel-length.

Combining experimental data from Chapters 3 and 4 with previous literature allows for speculation of the acquisition process of inflectional morphology including morphophonological alternations. Previously it has been assumed that representations of all complex forms begin as unanalysed units in the child's lexicon (cf. Dressler & Karpf, 1994). This assumption is potentially called into question by the finding (cf. Chapter 2 and Marquis & Shi, 2012) that infants possess an early sensitivity to morphological structure. If infants possess some early morphological knowledge, and this is indeed morphological knowledge, it seems likely that they will make use of this skill. As such, they will retain some ability to conduct basic morphological analyses of lexical items and posit links between members of an inflectional paradigm. Without semantic knowledge of the inflectional affix (e.g. that it indicates a number difference) they will at least be able to form a generalisation that a complex word contains a stem and an affix. This does not rule out the possibility that complex words are represented in their whole form as well as a stem + affix combination. Indeed, this is probable, but crucially children are aware that there is a semantic link between these forms. With the acquisition of morphological and semantic knowledge the learner will become aware of the function and productivity of a given morpheme. For example they are in a state to learn that *-en* means 'more than one', and it is a productive suffix that can be applied across the board. Accordingly, if the plural of [pɛt] is [pɛt-ən], then the plural of [bɛt] must be [bɛt-ən].

At the same time, children also hear complex words with medial voicing; they encounter the form *bedden* in their input. It is logical that these forms will initially be represented in their whole form as the link between simple and complex form is less transparent (cf. Baayen et al., 2003). At this stage the learner has two competing forms in their mental lexicon; one that they can form through generalisations of morphological processes, and the other from their environment. Overgeneralisation of voicing alternations to non-alternating forms only minimally occurs; forms such as **pedden* are neither heard in the input nor generated by the generalisation of stem + en. This is the point that was captured for Dutch children in Chapter 3. At this point children were aware of the semantic equivalence of these two competing forms; both *betten* and *bedden* facilitated lexical access equally. This indicates acceptance of intraparadigmatic alternations, without being able to specify the specific lexical items it applies to.

From this point on the learner possesses all of the knowledge and skills needed, and the task at hand now is to specify which lexical items contain an alternation. This will be a gradual process, working across the lexicon and sensitive to properties of lexical or phonotactic frequency. The exact mechanism at play is open to debate. Jarosz (2011), Peperkamp and Dupoux (2002) and Tesar and Prince (2003) would argue that lexical specification involves restructuring the underlying representation of stem-final voicing in a lexical item. Where a lexical representation was initially specified for /t/ in the absence of counterevidence, it can now be specified as /d/. The alternative is that learners do not restructure their lexical representation but the plural form containing voicing is strengthened by frequency and associations within the lexicon, ensuring that this route is faster than a parsing route in lexical access (cf. Bybee, 1995). Either of these interpretations could account for the data in Chapter 3 and 4: at a certain point children know whether a plural form contains a voicing alternation or not, and reject a mispronunciation. The experimental paradigm used is not sensitive enough to distinguish between the two approaches, and further studies would be needed in order to do so. However, the restructuring of underlying representations hypothesis as described by Jarosz (2011), Peperkamp and Dupoux (2002) or Tesar and Prince (2004) needs modifying to incorporate the gradual nature of the restructuring process and the influence of (language-specific) distributional properties.

1)	/pɛt/		/pɛt-ən/	Basic morphological analysis.	
2)	/pɛt/ /bɛt/	↔	/pɛt-ən/ /bɛdən/	[ən] is functional, *pet* and *petten* are related. Voicing is contrastive, *bet* and *bedden* are not related.	German 9-month-olds, Chapter 2
3)			-en is a plural suffix, meaning ‘more than one’		
4)	/pɛt/ /bɛt/ /bɛt/	↔ ↔ ↔	/pɛt-ən/ /bɛt-ən/ /bɛdən/	Generalisation: *bet* is to *betten* what *pet* is to *petten*. Semantic link between *bet* and *bedden* also noticed, but *bedden* represented as full-form.	Dutch 3-year-olds, Chapter 3
5a)	/pɛt/ /bɛt/	↔ ↔	/pɛt-ən/ /bɛdən/	*betten* falls away as paradigmatic link between *bet* and *bedden* strengthened.	German 3-year-olds, Chapter 3.
6b)	/pɛt/ /bɛd/	↔ ↔	/pɛt-ən/ /bɛd-ən/	*betten* falls away as /bɛt/ restructured to /bɛd/ and final-devoicing. Link between /bɛd/ and /bɛdən/ transparent.	Dutch 3-year-olds in post-sonorant context, Chapter 4

Figure 1. Schematic diagram of the course of acquisition of voicing alternations in plural forms.

5. Concluding remarks

This thesis has investigated the question of how non-allophonic morphophonological alternations are acquired in two different languages, adding new insights to debates concerning the interaction of phonology and morphology in acquisition, and the nature of morphological representations in the mental lexicon. By comparing a similar phenomenon in two closely related languages it was possible to make, and empirically test, predictions relating to the effect of differences in the morphological and phonological systems of the two languages during acquisition. Naturally, in doing so new questions and predictions for future research also arose, underlining, among other things, the importance of cross-linguistic studies and systematic investigation of different linguistic domains.

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Samenvatting

Kinderen leren hun moedertaal snel en ogenschijnlijk moeiteloos; binnen een korte periode kunnen ze zowel taal begrijpen als taal inzetten om zich uit te drukken. Dit is een enorme prestatie waarvoor verschillende complexe cognitieve processen samen moeten komen. In het eerste levensjaar maken baby's grote sprongen in het verwerven van hun moedertaal. Ze leren bijvoorbeeld welke fonemen hun taal heeft, dat wil zeggen welke klanken een onderscheidende betekenis hebben (bijv. /d/ en /t/ in *dak* vs. *tak*), en hoe woorden uit fonemen zijn opgebouwd. Taal bestaat niet uit losse woorden, maar uit complexe uitdrukkingen van zinnen met meerdere woorden waarbij er in gesproken taal geen duidelijke pauzes tussen woorden zijn (in vergelijking met geschreven taal waar spaties de woordgrenzen aangeven). Binnen het eerst levensjaar leren baby's ook woorden uit spraak te segmenteren en maken ze de eerste stappen in het begrijpen van woordbetekenis. Woorden kunnen verschillende vormen aannemen afhankelijk van de andere woorden in de zin. Het verbuigen en vervoegen van woorden is nodig om een grammaticale zin te maken (bijv. *ik heb* vs. *jij hebt*). Hoewel de structuur van het woord verandert, blijft de basisbetekenis hetzelfde (e.g. *auto* en *auto's* zijn allebei voertuigen, het verschil ligt in hoeveel het er zijn). Ook het verwerven van deze kennis begint in de laatste maanden van het eerste jaar. Op basis van deze eerste sprongen kan de dreumes zijn eerste (herkenbare) woorden zeggen, groeit zijn woordenschat enorm en leert hij om zelf woorden samen te stellen in zinnen van toenemende complexiteit.

Vaak vinden er veranderingen plaats in de fonetische vorm van een woord of morfeem, gestuurd door interactie met omliggende woorden en morfemen. Dit proefschrift onderzoekt het verwerven van een morfofonologische alternatie in het Nederlands en het Duits. Zoals in veel talen maken het Nederlands en het Duits onderscheid tussen stemhebbende (/b,d,g,v,z,ɣ/) en stemloze (/p,t,k,f,s,x/) medeklinkers. Echter, in deze talen wordt het contrast geneutraliseerd aan het eind van een woord of lettergreep. In deze positie mogen slechts stemloze medeklinkers gebruikt worden. Het woord *bed* wordt bijvoorbeeld uitgesproken als [bɛt]. In bepaalde meervoudsvormen wordt er een lettergreep aan de enkelvoudsvorm toegevoegd. De /d/ staat daardoor niet meer in een finale positie en neutralisatie is niet meer van toepassing, dat wil zeggen dat de laatste medeklinker niet stemloos wordt gemaakt (bijv. *bedden,* [bɛdən]). Vergelijk nu het woord *pet* met *bed.* In het enkelvoud eindigen ze allebei op een [t]; [pɛt] en [bɛt]. De meervoudsvorm van *pet* is echter *petten* en geen **pedden.* Eindklankverscherping (final devoicing of Auslautverhärtung) gebeurt door het hele lexicon (bijv. *heb/hebben, hard/harder*), maar dit proefschrift beperkt zich tot het verwerving van alternaties in zelfstandige naamwoorden.

Kinderen leren van zelfstandige naamwoorden vaak eerst het enkelvoud en pas later het meervoud. De enkelvoudsvormen van woorden zoals [pɛt] en [bɛt] bevatten niet genoeg informatie om een keuze voor een meervoudsvorm met een [t] danwel een [d] te kunnen maken. Welke meervoudsvorm de juiste is, wordt pas duidelijk als ze meer vormen van het morfologisch paradigma kennen, en de cognitieve capaciteiten hebben om deze met elkaar te kunnen vergelijken. Dit proces vraagt om ingewikkelde cognitieve vaardigheden die naar verluidt pas in de puberteit volledig ontwikkeld zijn (Pierrehumbert, 2003). Hoe Nederlands- en Duitstalige kinderen de alternatie leren vormt de kernvraag van dit proefschrift. Er wordt gekeken naar de kennis van alternaties in twee leeftijdsgroepen om het ontwikkelingsproces te kunnen volgen. Het doel van de vergelijking van deze twee talen is het onderzoeken van de rol die respectievelijk taalspecifieke factoren en de algemene cognitieve ontwikkeling in dit verwervingsproces spelen.

Nederlands en Duits zijn nauw verwante talen. Desondanks zijn er in hun fonologie en morfologie verschillen tussen de talen die op hun beurt tot verschillen in het verwervingsproces van morfofonologische alternaties zouden kunnen leiden. Ten eerste is er een verschil in hoe belangrijk het stemhebbendheid contrast is in de beide talen. Het contrast is in het Duits belangrijker dan in het Nederlands, waar vooral in de wrijfklanken of fricatieven (/f,v,s,z,x,ɣ/) het verschil niet meer essentieel is. Er zijn weinig woordparen die zich van elkaar onderscheiden alleen op basis van de stemhebbendheid van fricatieven, zoals *sussen* en *zussen* voor sommige sprekers. Echter, in veel regio's van Nederland is het contrast stemhebbendheid in fricatieven verdwenen en worden deze twee woorden uitgesproken zijn met een initiale [s] (van de Velde, Gerritsen, & van Hout, 1996). Ook de categorie van plofklanken (/p,b,t,d,k,g/) wordt niet volledig gebruikt in het Nederlands, waarin /g/, zoals in *goal* uitgesproken, geen moedertaalfoneem is.

Duits heeft het contrast stemhebbendheid nog wel volledig in de plof- en wrijfklanken. Daardoor krijgen Duitse kinderen het contrast vaker te horen, wat ze eventueel zouden kunnen gebruiken bij het leren van alternaties.

De morfologie van het Duits is complexer dan die van het Nederlands. Er zijn twee frequente meervoudssuffixen in het Nederlands (*-en* en *–s*) en vijf in het Duits (*-e -er, -n/en, -s*, en -). Daarnaast kan ereen verandering in de klinker komen door middel van een umlaut om, soms ook in combinatie met suffixatie, een meervoud te creëren (*Baum-Bäume).* Verder zijn grammaticale naamvallen, geslacht en nummer verplicht gemarkeerd op zelfstandige naamwoorden, bijvoeglijke naamwoorden en werkwoorden.

Een voorspelling die in dit proefschrift wordt onderzocht is dat Duitse kinderen in de vroege verwerving van de stemhebbend alternatie baat hebben bij de variatie in de fonologische en morfologische systemen van het Duits, in vergelijking met Nederlandse kinderen omdat hun taal meer variatie in de fonologie en morfologie bevat.

Hoofdstuk 2 onderzoekt of Duitse en Nederlandse baby's van negen maanden oud al op deze jonge leeftijd kennis hebben van inflectie en de stemhebbendheid alternatie. Om dit te testen is de voorkeurskant-kijken- procedure gebruikt (Jusczyk, Houston, & Newsome, 1999). In deze methode hoorden baby's twee korte verhaaltjes, en in elk verhaaltje kwam een bepaald woord meerdere keren voor; de zogeheten familiarisatiefase. Vervolgens hoorden de baby's in de testfase vier woorden, waarvan er twee uit de verhaaltjes kwamen en er twee nieuw waren. Er werd gemeten hoe lang de baby's naar de bekende en nieuwe woorden luisterden, waarbij de verwachting was dat de luistertijd tussen de twee zou verschillen als ze de woorden uit de verhaaltjes herkenden. Om morfologische kennis te onderzoeken hebben wij deze methode enigszins aangepast. In plaats van precies dezelfde woorden te horen, kregen baby's in de testfase een geïnflecteerde vorm aangeboden. Ter illustratie, ze hoorden bijvoorbeeld "dot" tijdens de familiarisatiefase, en "dotten" tijdens de testfase. In een tweede conditie hebben wij ook een stemhebbendheid alternatie toegevoegd; na "dot" hoorden ze "dodden". In beide gevallen zijn de geïnflecteerde vormen mogelijke meervoudsvormen van het gefamiliariseerde woord.

Uit eerder onderzoek met Frans-lerende baby's blijkt dat ze al een zekere voorkennis van inflectie hebben (Marquis & Shi, 2012). Op basis hiervan was de voorspelling in hoofdstuk 2 dat zowel Nederlandse als Duitse baby's testwoorden zouden herkennen in de conditie zonder alternaties, maar dat de twee taalgroepen zich zouden onderscheiden in de conditie met alternaties, omdat de morfologische en fonologische systemen verschillen. Maar in tegenstelling tot wat we verwacht hadden, herkenden Nederlandse baby's de testwoorden in zowel de eerste als de tweede conditie niet. Duitse baby's daarentegen herkenden de testwoorden wel als ze vervoegd waren, maar niet als er een stemhebbendheid alternatie plaatsvond tussen de familiarisatie- en testfasen. Negen-maanden-oude Duitse baby's hebben dus een vroege vorm van kennis van inflectie en kunnen een verband tussen woordvormen herkennen dat vergelijkbaar is met het verschil tussen enkelvouds- en meervoudsvormen. Maar, op dit punt in hun taalontwikkeling hebben ze (nog) geen kennis van de stemhebbendheid alternatie. Het contrast tussen stemloze en stemhebbende medeklinkers is blijkbaar relevant voor Duitse baby's en ze behandelen [t] en [d] alleen als betekenisonderscheidende fonemen.

Hoofdstuk 3 kijkt naar een later moment in de ontwikkeling en onderzoekt de kennis van stemhebbendheid alternaties van Nederlandse en Duitse peuters. De sterkte van hun lexicale representaties werd onderzocht door middel van een perceptie- experiment in combinatie met een corpusanalyse van kindgerichte spraak in beide talen. Uit de corpusanalyse bleek dat Duitse kinderen meer voorbeelden van woorden met een stemhebbendheid alternatie horen dan Nederlandse kinderen. Dit leidde, samen met de bovengenoemde verschillen in fonologie en morfologie, tot de voorspelling dat Duitse kinderen meer kennis van alternaties in bekende woorden zouden hebben in vergelijking met Nederlandse kinderen van dezelfde leeftijd.

Peuters van drie jaar deden een kiezend-kijken-experiment waarin ze telkens twee plaatjes op een computerscherm aangeboden kregen. Een van de plaatjes werd benoemd, en het kind werd geacht naar het benoemde plaatje te kijken. Daarbij werden hun oogbewegingen automatisch gemeten om te kunnen bepalen naar welke plaatje ze keken en om het tijdsverloop van hun kijkgedrag te zien. In sommige trials werd een woord verkeerd uitgesproken. Het kind hoorde bijvoorbeeld **gieder* in plaats van *gieter*. Als ze minder snel naar het plaatje van de gieter zouden kijken als ze **gieder* hoorden in plaats van *gieter*, zou dit aantonen dat hun lexicale representatie van *gieter* specificeert dat de mediale medeklinker een [t] moet zijn en geen [d]. Daarnaast kregen ze trials met woorden in het meervoud, bijvoorbeeld *petten* en *bedden*, met ook af en toe een verkeerde uitspraak zoals **pedden* en **bedden*. Nederlandse kinderen merkten de verkeerde uitspraak op in monomorfemische woorden met een /t/ (*gieter*/**gieder*) en /d/ (*ridder*/**ritter*), en meervoudsvormen met een /t/ (*petten*/**pedden*). Ze merkten het niet als *bedden* aangeboden werd als **betten*; ze keken in beide gevallen naar het plaatje van twee bedden. Dit resultaat volgt het patroon dat al eerder gerapporteerd is in de producties van kinderen van deze leeftijd (e.g. Kerkhoff, 2007); ze zeggen zelf vaak **betten* of **hoeten*. Deze vormen zijn een logische generalisatie van patronen in de taal, waardoor het meervoud wordt gemaakt door de enkelvoudsvorm met het suffix *–en.* Ze weten nog niet zeker of de juiste vorm een stemhebbendheid alternatie nodig heeft, maar ze accepteren deze mogelijkheid. Ze kijken zowel naar *bedden* als **betten*, maar ze kijken niet naar **pedden*. Het blijkt dat kinderen van 3 jaar weten dat in sommige woorden een alternatie voorkomt en in sommige niet. Ze weten waar het niet van toepassing is, maar twijfelen nog over de woorden waar het wel verplicht is.

Duitse kleuters deden hetzelfde experiment met Duitse woorden. Het blijkt dat zij, zoals verwacht, sterkere lexicale representaties hebben van stemhebbendheid alternaties in meervoudsvormen, en zij laten een significant verschil in hun kijkgedrag zien bij de juiste en verkeerde uitspraak van meervoudsvormen met zowel een /t/ als een /d/, bijvoorbeeld *Betten-*Bedden* of *Hunde-*Hunte.*

Hoofdstuk 4 onderzoekt ook peuters van 3 jaar, maar alleen in het Nederlands. In dit hoofdstuk wordt bekeken of peuters de fonotactische structuur van een woord kunnen gebruiken om de aanwezigheid van een stemhebbendheidalternatie te voorspellen. Fonotactische waarschijnlijkheid is de kans dat bepaalde klanken samen voorkomen. In dit geval: wat is de kans dat een finale [t] een [d] moet zijn in de complexe vorm, en valt dit te voorspellen op basis van de voorgaande klank? In een studie met volwassenen lieten Ernestus en Baayen (2003) aan de hand van corpusdata zien dat stemhebbendheid alternaties niet willekeurig zijn. Er zijn duidelijke patronen, bijvoorbeeld dat na een neusklank (/m,n/) of vloeiklank (/l,r/) een alternatie frequenter is dan na een klinker; *hond-honden* (met alternatie) en *pet-petten* (zonder alternatie) volgen dus het dominante patroon in de taal. Als volwassenen een onzinwoord moeten inflecteren, maken ze gebruik van deze patronen. Ook baby's maken gebruik van fonotactische informatie, onder andere om woordgrenzen te zoeken (Mattys & Jusczyk, 2001) en nieuwe woorden te leren (Storkel, 2003).

De onderzoeksvraag in dit hoofdstuk was of de taalinput die Nederlandse peuters krijgen genoeg informatie bevat over de voorspelbaarheid van de aan- of afwezigheid van een stemhebbendheid alternatie, en zo ja of peuters deze informatie kunnen gebruiken. Een corpusanalyse van enkelvoud-meervoudsparen in kindgerichte spraak toonde aan dat er in de woorden die kinderen horen een verschil is in de waarschijnlijkheid van een alternatie. Peuters deden twee experimenten. Eerst deden zij een productietaak waarin ze paren van twee kaartjes moesten zoeken en het plaatje op de kaartjes in het enkelvoud en meervoud moesten benoemen. Voor één groep kinderen eindigden alle woorden met een klinker gevolgd door een [t], bijvoorbeeld *pet, bed*, en een tweede groep kinderen kreeg woorden met een [n], [l] of [r] voor de finale [t], zoals *tent* en *hond.* In een tweede experiment deden dezelfde kinderen een zelfde soort perceptie-experiment als in hoofdstuk 2 waar ze zowel juiste als verkeerde uitspraken van woorden hoorden en vervolgens naar het goede plaatje moesten kijken. Ook hier waren de kinderen in twee groepen verdeeld; die met klinkers voor de [t]/[d] en die met medeklinkers voor de [t]/[d].

In hun productie maakten kinderen gebruik van de voorspelbaarheid van stemhebbendheid alternaties. Ze realiseerden woorden zoals *honden* vaker op de juiste manier (met een [d]) dan woorden zoals *bedden,* in plaats waarvan ze vaak **betten* zeiden. Hoewel ze bijna nooit **pedden* zeiden, zeiden ze af en toe **tenden.* Dit is een overgeneralisatie van de vaker voorkomende vorm. In het perceptie-experiment merkten kinderen het in beide condities (**pedden* en **tenden*) op als een [t] verkeerd uitgesproken werd. Als [d] uitgesproken werd als [t] merkten ze dat alleen in de nasale context op; ze wisten dus dat **honten* verkeerd is, maar waren er minder zeker van dat **betten* niet goed is. Dit patroon kwam overeen met hun eigen producties, maar het effect was groter wanneer kijkgedrag gemeten werd in plaats van wanneer een expliciet antwoord van het kind gevraagd werd. Beide experimenten laten zien dat kinderen gevoelig zijn voor fonotactisch patronen en dat ze gebruik maken van deze informatie in de verwerving van morfofonologische alternaties.

Op basis van de drie experimentele hoofdstukken kunnen er drie algemene conclusies getrokken worden over de rol van de moedertaal, de functie van fonotactische waarschijnlijkheid en de ontwikkeling van taalproductie en -perceptie in het specifieke geval van de verwerving van morfofonologische alternaties. Deze conclusies versterken soortgelijke conclusies in andere gebieden van taalverwervingsonderzoek.

1. De moedertaal heeft een belangrijke rol bij het verwerven van morfofonologische alternaties.

Cross-linguïstische verschillen in het verwerven van morfofonologische alternaties werden onderzocht in hoofdstuk 2 en 3. Op beide leeftijden presteerden Duitse kinderen beter dan hun Nederlandse leeftijdsgenoten; dit duidt erop dat kennis van inflectie, in het bijzonder alternaties, sneller wordt geleerd door Duitse baby's dan Nederlandse baby's. Duitse kinderen krijgen meer evidentie dat het stemhebbendheid contrast belangrijk is in hun taal, dat inflectie verplicht en hoogfrequent is, en dat stemhebbendheid alternaties voorkomen en in welke woorden. Dat wil niet zeggen dat Duits kinderen "beter" zijn in het verwerven van taal. In het kleine gebied van stemhebbendheid alternaties hebben Duits lerende baby's een voorsprong, maar dat wordt later ingehaald door Nederlands lerende baby's. De resultaten van hoofdstukken 2 en 3 spreken voor het feit dat baby's al op jonge leeftijd gevoelig zijn voor de eigenschappen van hun moedertaal en minder aandacht besteden aan minder belangrijke elementen.

2. Peuters zijn gevoelig voor fonotactische waarschijnlijkheden in het verwerven van morfofonologische alternaties.

Ondanks de conclusie dat Duitse kinderen het makkelijker vinden om de stemhebbendheid alternatie te leren, blijven Nederlandse peuters niet helemaal achter. Ze maken gebruik van de signalen die ze krijgen en van de dominante patronen die ze uit hun omgeving oppikken. Dit heeft invloed op het verwervingsproces. Ze gaan na in welke context een alternatie vaker voorkomt (of niet) en slaan deze informatie op in hun mentale lexicon. Deze bevinding laat zien dat kinderen, net als volwassenen, de aanwezigheid van een stemhebbendheid alternatie kunnen voorspellen op basis van de woordcontext. Ook volgt het de lijn van onderzoek die laat zien dat baby's en peuters gevoelig zijn voor fonotactische informatie.

3. Perceptie gaat vooraf aan productie in de verwerving van morfofonologische alternaties.

In hoofdstuk 4 werd er een directe vergelijking gemaakt tussen hoe accuraat kinderen zijn in hun uitspraak van alternaties en wat ze hebben opgeslagen in hun mentale lexicon. Het is al lang bekend dat kinderen meer begrijpen dan wat ze kunnen zeggen, maar eerder onderzoek naar morfofonologische alternaties heeft voornamelijk naar productie gekeken. De link tussen perceptie en productie en de link tussen de twee is nog nauwelijks onderzocht. Door alleen naar productie te kijken wordt de kennis van een kind onderschat.

Het verzamelen van deze morfofonologische data van Nederlandse en Duitse kinderen, en het bij elkaar brengen van perceptie- en productiedata leidt tot unieke inzichten in de verwerving van de kennis van morfofonologische alternaties.

Curriculum Vitae

Helen Buckler was born on 2nd October 1984 in Peterborough, England. She attended the St John Fisher RC Comprehensive School and The Kings' School, both in Peterborough, before spending a year working as an au pair in Germany. In 2008 she received a BA in German & Linguistics, and in 2009 an MA in Languages & Linguistics from the University of Manchester, UK. As an undergraduate she also spent a year studying at the University of Leipzig, Germany as part of the Erasmus Exchange programme. In 2009 she was awarded a fellowship from the International Max Planck Research School for Language Sciences to undertake doctoral research at the Radboud University Nijmegen and Max Planck Institute for Psycholinguistics, the Netherlands. As part of this research she spent 6 months as a visiting researcher at the BabyLab of the University of Potsdam, Germany. She currently works as a Postdoctoral Fellow in the Child Language and Speech Studies Lab at the University of Toronto Mississauga.

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