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The onset of word form recognition: A behavioural and neurophysiological study[1]

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Abstract

It has long been known that word learning under natural circumstances is characterised by a slow start followed by a steeply rising curve. Previous studies using the head turn procedure (HT) have shown that both English and French infants show word form recognition by 11 months but Welsh infants show the effect only at 12 months. Furthermore, a study using event-related potentials (ERPs) showed that at 11 months English infants detect the difference between familiar and rare words within 250 ms of stimulus onset. The experiments reported here were designed to provide an exhaustive exploration, in English and Welsh, of the timing and nature of the earliest word form recognition and the neurophysiological mechanisms involved. Use of ERPs alongside HT made it possible to detect implicit attentional responses to words heard frequently in the home at an age when word knowledge is not yet commonly reported and novel form-meaning pairings are not yet readily trained. Overall the HT and ERP findings corroborated each other well throughout the age groups studied in both languages. In a cross-sectional study we replicated the familiarity effect in English, showing that the onset of word form recognition is reliably found in HT at 11 months. In addition, we found localised signs of a familiarity effect at 9 months and a main effect of familiarity at 10 months with ERPs. Remarkably, word familiarity effects are seen in neither HT nor ERPs at 12 months, just one month after they appear in their most robust form. In Welsh infants we failed to obtain a significant word form recognition effect at any age in either the HT or the ERP procedure, although localized ERP effects were seen at 11 months. Study of a sample of 11-month-old Welsh-English bilingual infants showed a significant familiarity effect in both English and Welsh and in both HT and ERPs. The behavioural and electrophysiological patterns of bilinguals resemble those of English and Welsh monolinguals, although the HT effect for Welsh was marginally significant in this case. In the ERPs, the findings are quite similar to those of the English monolinguals but differ from those of the Welsh monolinguals. Indeed, in bilingual infants exposed to Welsh we found significant ERP familiarity effects which were maximal at ca. 270 ms and 560 ms, i.e. significantly later than those seen for English. We speculate that the delay in word form recognition in Welsh may be due to the infants' receiving monolingual input in

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homes situated within a bilingual community. On the other hand, bilingual home exposure in this same community appears to result in earlier word form recognition than is found for Welsh only. We interpret the differences between English and Welsh in the neural time course of word form recognition revealed by the ERPs as relating to the differences in accentual pattern in the two languages. In brief, our studies provide a time-line of single word form recognition which is strongly influenced by characteristics of both the sociolinguistic situation and the ambient language itself.

Introduction

It has long been known that word learning under natural circumstances is characterised by a slow start followed by a steeply rising curve (Lewis, 1936; Oviatt, 1980). The studies that we report here were designed to provide an exhaustive exploration, in two language groups, of the timing of the earliest word form recognition based on frequent exposure in the course of the infant's daily life and the neurophysiological mechanisms involved. Use of Event Related Potentials (ERPs) with infants, alongside the Head Turn procedure (HT), makes it possible to detect implicit attentional responses to words heard frequently in the home at an age when word knowledge is not yet widely reported and novel form-meaning pairings are not yet readily trained. Our primary goal was to map the interaction between infant response to word form over the course of the 'slow start' and to explore language group differences in the onset of word form recognition.

Early advances in linguistic knowledge as revealed by the Head Turn procedure

Experimental studies of infant speech perception have taught us a great deal about changes in infant responses to speech over the course of the first year of life (Jusczyk, 1997; Vihman, 1996). We know that at birth or within the first one or two months of life infants already respond to both the rhythms of the native language and the affective meanings they express (Fernald, 1992; Mehler et al., 1988; Ramus, 2002). Furthermore, it is only in the second half of the first year that infants begin to respond with greater attention (as measured through longer head turns toward a sound source) to the typical prosody of native language content words over less typical prosody (Jusczyk, Cutler & Redanz, 1993), to narrative passages incorporating words trained in the laboratory (Jusczyk & Aslin, 1996; Polka & Sundara, 2003; cf. chapters by Nazzi et al. and Cutler et al., this volume), and to phonotactic patterns typical of their language (Jusczyk et al., 1993; Jusczyk, Luce & Charles-Luce, 1994; Mattys & Jusczyk, 2001). We also know that by the end of the first year infants no longer discriminate consonantal contrasts not found in the native language, although this capacity is seen up to age 8 or 10 months (Werker & Tees, 1984; Best, 1994); the change is generally interpreted as a narrowing of attention (Werker & Pegg, 1992). Finally, work with 'artificial languages', or sequences of syllables strung together according to an invented 'grammar', has shown that infants, like adults, are able to learn the distributional patterns of such sequences (Saffran, Aslin & Newport, 1996). Those findings shed new light on infant phonological and lexical learning in the first year, suggesting a critical distinction between the *rapid advances in implicit knowledge* of different aspects of ambient language sequential patterning (prosodic, segmental, phonotactic), in the absence of either voluntary attention or an intent to learn, and the *more gradual learning of particular form-meaning correspondences* in the second year, when infants actively seek to know the 'names of things' (Macnamara, 1982, Vihman & McCune, 1994).

The 'preferential' head-turn procedure, on which most of the experimental findings mentioned above are based, has also been used to elicit an attentional response to untrained 'familiar words' (or phrases), lexical units whose form is retained from infants' everyday experiences. Experimentally, these words are tested in contrast with phonotactically matched rare words, or words no infant would be expected to have heard with any regularity (Hallé & Boysson-Bardies, 1994). In our laboratory in North-Wales, using the same paradigm with infants exposed to British English, we replicated Hallé and Boysson-Bardies' finding that 11-month-olds recognize such untrained words in the absence of any situational cues but we failed to elicit the response in 9-month-olds (Vihman, Nakai, DePaolis & Hallé, 2004). In a parallel study with Welsh infants we found word form recognition at 12 but not at 11 months (Vihman & DePaolis, 1999). We interpret the differential response to familiar words at 11 (English) or 12 months (Welsh) as evidence for word form recognition but not necessarily for comprehension. Such dawning awareness of particular word forms might constitute a bridge between the implicit knowledge of linguistic patterning reviewed above and the explicit demand for words, communicated through pointing, grunting, or phrases such as 'whazis?', which accompanies the lexical spurt often seen by 17-18 months (McCune, Vihman, Roug-Hellichius & Delery, 1996).

Werker and her colleagues (Stager & Werker, 1997; Werker, Cohen, Lloyd, Casasola & Stager, 1998; Werker, Fennell, Corcoran & Stager, 2002) have used a preferential looking paradigm to explore the onset of children's ability to 'fast-map' or rapidly learn arbitrary form-meaning relationships. They found that although both 8- and 14-month-old infants can *discriminate* minimal pairs (as can younger infants as well: Jusczyk, 1997), infants can learn to *link arbitrary nonword forms with meanings* (based on training with novel objects) only at 14 months – and then only if the nonsense stimuli are *non-minimal pairs*. Infants can associate *minimally distinct* word forms (*bih-dih*) to meanings by 17 months. Furthermore, Nazzi et al. (2005) have shown that even at 20 months infants learning French can learn minimal pairs which differ by a *single consonant* but not those which differ by a *single vowel*. Clearly the word learning trajectory changes rapidly over this period.

Finally, as early as 7.5 months infants can be trained by repeated exposure to word forms presented in isolation to segment those words out of a brief narrative (Jusczyk & Aslin, 1995), but the recognition of *untrained word forms* presented in isolation emerges only between 9 and 11 months. Furthermore, the ability to segment familiar words from a brief passage *without training* also emerges later, at 11-12 months (DePaolis & Vihman, 2006.) Holistic form-meaning association is seen experimentally at 15 months (Schafer & Plunkett, 1998 – but see Schafer, 2005, for evidence that focused training in the home over the last three months of the first year can result in precocious generalised word comprehension) and the learning of more finely distinguished novel form-meaning pairings only by 17 months. Earlier experimental work investigating the origins of word comprehension suggested a similar trajectory, with considerably more rapid new word learning in the period 15-17 months (Oviatt, 1980).

Word recognition as revealed by ERPs

In an attempt to gain complementary insight at the neurophysiological level we designed a first ERP study to identify the neural time-course of the familiarity effect found in HT (Thierry, Vihman & Roberts, 2003). Based on previous studies by Mills et al. (1997), we expected to see familiar words elicit negative shifts of amplitude relative to rare words ca. 200 ms after stimulus onset. We presented 18 English 11-month-olds with 56 familiar words (based on The MacArthur Communicative Development Inventory [CDI] adapted for British English: Hamilton, Plunkett & Schafer, 2001) and 56 phonotactically matched rare words. We observed a succession of four peaks labelled P1, N2, P3 and N4 for descriptive purposes (Fig. 1). The main result from this study was an increase in amplitude of the N2 peak which extended into the P3 window, resulting in a familiarity main effect significant between 170 and 248 ms after stimulus onset (based on ms-by-ms t-tests).

Figure 1 about here

We interpreted the N2 modulation as a Mismatch Negativity (MMN; see Näätänen, 2001, for a review). The MMN is an ERP modulation typically observed between 100 and 250 ms after the onset of a stimulus of low local probability presented within a stream of stimuli of high local probability (Näätänen et al., 1979). The MMN requires no involvement of conscious attention; it is thought to be wholly automatic and reliant on the spontaneous evaluation of perceptual cues by the auditory system. Furthermore, the MMN has been reliably identified using simple harmonic tones in newborns and can be found throughout the first year of life (Kushnerenko et al., 2002; see also Thierry, 2005). Here we interpreted the N2 modulation as an MMN because any one infant tested was unlikely to be familiar with all of the stimuli selected as 'familiar'. Since the subset of word stimuli that were actually familiar to a given child would thus have been of low local probability for individual infants, these words would have elicited an MMN which survived the averaging process and emerged in the form of an N2 modulation. To account for the remarkable speed of the discrimination observed, we proposed that the time-course of the familiarity effect (peaking ca. 200 ms) was dependent upon the degree of statistical phonological overlap between familiar and rare words. Indeed while fully 72% of the familiar words shared their initial phoneme with a rare word, only 36% shared their second phoneme and 5% their third[2]. Thus it is plausible to conclude that the infants showed automatic familiarity responses within the period of the first few phonemes. This interpretation should be kept in mind when we discuss the response pattern seen in Welsh infants.

Taken together, the HT and ERP results suggest that familiar words are recognised at around 11 months in English, i.e., not long before the typical onset age for word production (ca. 12 months). Furthermore, the basis for the HT effect appears

[2] So, for example, *again* could immediately be distinguished from all of the rare words, since no rare word began with unstressed schwa, while *blanket* vs. *blindfold, bottle* vs. *balmy* or *car* vs. *carnal* (in an English dialect that lacks post-vocalic /r/) could only be distinguished after the occurrence of the second segment.

to be an automatic involvement of attention based on the implicit detection of familiar perceptual cues rather than a voluntary orientation mechanism. The difference in the HT results for English vs. Welsh is interesting since it indicates that not all languages yield the familiarity response on the same developmental time-course. However, since the samples used in the HT studies were small (12 infants) and the relative familiarity of the stimuli used in the HT studies of English, French and Welsh was uncontrolled, we planned more systematic experimentation over a longer period and with larger samples of infants. Furthermore, the disparity between the HT results in English vs. Welsh had yet to receive validation at the neurophysiological level.

Onset of word recognition in English and Welsh

Here we sought to determine the age at which the first neurophysiological and behavioural signs of untrained familiar word recognition can be found in English and Welsh. In these studies we replicated and expanded previous findings with English-learning infants recruited from the bilingual community of North Wales by testing cross-sectional samples of 9-, 10-, 11- and 12-month-olds on their response to familiar and rare words. In addition, we tested 9-, 10-, 11- and 12-month-old Welsh infants from the same community, using the same technique and the same paradigm. 'Monolingual' infants were defined as those whose parents indicated more than 80% use of one language with the child (completely monolingual usage cannot always be found in this community; both children learning English and children learning Welsh sometimes produce one or two early words from the other language).

New stimuli were developed in both the English and Welsh studies, with the goal of arriving at a selection of familiar words well matched for relative frequency of use according to previous parental reports, so that age of onset of word recognition could be reliably equated across language groups. A list of 33 familiar and 33 rare words was recorded by three female native speakers for each language. Based on 158 CDIs returned for English infants participating in previous studies in our laboratory and 113 CDIs returned for Welsh infants, for each of the words used as 'familiar' stimuli in the experiments, an average of 36% of the parents of infants exposed only to English and 35% of the parents of infants exposed only to Welsh reported that the words were understood at ages 9, 10, 11 or 12 months. Testing consonants and vowels separately, we ascertained that the input frequency of the phonemes found in the familiar word stimuli was not different from that of those found in the rare word stimuli in either language. Acoustic analysis showed that there were no significant differences in loudness, pitch or duration between familiar and rare words.

English infants

Overall we tested 128 English infants. A total of 101 infants (25 9-, 27 10-, 23 11-, and 26 12-month olds) completed the HT test successfully and were included in the final analysis. A total of 81 infants (15 9-, 21 10-, 26 11-, and 19 12-month olds) completed the ERP test successfully and had enough artefact free trials to be included in the final analysis.

In HT, the difference in looking times to familiar vs. rare words reached significance only at 11 months (Fig. 2). This 11-month effect is robust in English, as we have found it repeatedly in experiments using different stimuli. In the present experiment the stimuli were increased from 12 (repeated across 6 trials in Vihman et al., 2004) to 33, with 11 stimuli in each of three trials, repeated once each; the increase in number of stimuli was due to the need to use the same words in HT as we used in ERPs, which require larger numbers (while minimizing repetition). Additionally, all of the words were recorded by three different female speakers, although in HT each child heard only one: This made it possible to present the stimuli in two blocks in the ERPs, one with each of two voices; the third voice was used for HT, with counterbalancing to ensure that no child heard any voice more than once in the two procedures and that all three voices were used in both procedures. Hence, in the ERP sessions infants heard 33 familiar words repeated once (66 trials, 50%) and 33 rare words repeated once (66 trials, 50%). We found that the variability in voice in HTs led to variability in familiarity effects across infants, although the subgroups of infants hearing each of the voices were not large enough to test for significance independently of the larger group. Furthermore, we found that the effect size at 11 months was smaller than in previous studies (Vihman, Thierry, Lum & Keren-Portnoy, in press). This is likely due to the fact that there were more words presented in this case, with fewer opportunities for infants to hear words they knew.

Figure 2 about here

Interestingly, after its robust appearance at 11 months the familiarity effect was no longer seen at 12 months, suggesting that exposure to the form of words alone no longer held the infants' attention at this age, when word meanings have begun to be learned more generally (Oviatt, 1980; Schafer, 2005). One reason for suspecting that this is the reason for the absence of the effect at that age is the decrease in overall looking time to both familiar and rare words in the experiment.

The pattern of HT results was strongly corroborated and supplemented by the ERP data (Figs. 3 and 4). First, we replicated Thierry et al. (2003), since a significant main effect of familiarity on N2 mean peak amplitudes[3] was found at 11 months. In addition, we found a new main effect of familiarity on N2 mean peak amplitude at 10 months. Furthermore, a significant familiar vs. rare N2 amplitude difference was found at electrode AF4 (right anterior frontal) already in 9-month-olds (a difference that survived correction for multiple comparisons).

Figure 3 and 4 about here

On Figure 4 the N2 effect can be seen to increase steadily in size from 9 to 11 months (see Fig. 4b, where the difference between familiar and rare words reaches its maximum at 11 months). The N2 effect then disappears entirely at 12 months. As in Thierry et al. (2003), we interpret the N2 effect as an MMN-like event, showing

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[3] As in Thierry et al., we label the peaks according to their order of appearance and polarity. N2 is therefore a descriptive label for the second peak with a negative polarity.

automatic orientation of the auditory system to (low-probability) recognizable stimuli presented amongst (high probability) unknown stimuli.

The progressive emergence of the familiarity effect shows that implicit word recognition commences well before 11 months over the right frontal hemi-scalp (Thierry et al, 2003; see Mills et al., 1997 and Thal et al, 1991 for discussion of the lateralisation of word familiarity effects in this age range). At 10 and 11 months the familiarity effect spreads broadly across the scalp, which suggests wider involvement of underlying cortical networks.

Interestingly, the N2 effect was accompanied by a developing N4 effect. No such effect was reported in Thierry et al. (2003). The immediate explanation for this apparent inconsistency comes from the data processing methods applied to the new monolingual dataset. Whereas the high pass digital filter used in Thierry et al. (2003) was set at 0.5 Hz, the filter used in the monolingual experiments was set at 0.3 Hz. The higher the cut off frequency of the filter, the cleaner the data, given that the wide amplitude waves which characterize infant EEG are greatly reduced by filtering in this frequency range. We chose to downgrade the filter to 0.3 Hz based on Friedrich and Friederici (2004, 2005), where use of such a filter allowed variations of the scale of the N400 to be measured and analyzed.

In the present study the N4 modulation became a significant main effect at 11 months and then – like the N2 –disappeared at 12 months. Furthermore, the size of the familiarity effect in the N2 range was significantly correlated with the size of the familiarity effect in the N4 range ($r=0.69$, $p<0.001$) across all age groups. The emergence of the N4 modulation at 11 months can be interpreted as reflecting increased infant familiarity with the second syllable (or the later part of the word more generally), a kind of pervasive N2 modulation. This view is supported by the significant correlation between N2 and N4 familiarity effects[4].

At 12 months the N2 and N4 disappear together. It is unlikely that words that sound familiar to a group of 11-month-olds suddenly become unfamiliar to a group of 12-month-olds. In the framework of our MMN-based interpretation of the N2-N4 complex we speculate that by 12 months a sufficient number of the intended 'familiar' words presented in the experiment have actually become familiar (to a sufficiently large number of infants) to eliminate the 'oddball' effect. That is, the probability of occurrence of familiar and rare words now becomes roughly equal, since we did actually present equal numbers of familiar and rare words. Under these conditions the MMN effect should no longer be expected – and it is not observed; this would explain why the two waveforms overlap so closely at 12 months. A critical test of this hypothesis would involve using a 'true' oddball paradigm at 12 months, i.e., by

[4] It should be noted again that N4 is a purely descriptive label; the N4 peak should not be confounded with the classical N400, which refers to a theoretical ERP modulation observed in experiments in which semantic context is manipulated. The N400, first reported by Kutas and Hillyard (1980), is particularly large when a word (or other meaningful stimulus) violates the semantic context in which it is presented (e.g., a sentence or a preceding picture). In infants, the N400 has not been observed before 14 months (Friedrich and Friederici, 2005) and its maximal sensitivity as measured in the picture-word priming paradigm is typically between 500 and 800 ms after word onset (see chapter by Manuela Friedrich in this volume).

presenting a small number of familiar words amidst a large number of phonotactically matched rare words.

Finally, in 12-months-olds we also noted a significant modulation between rare and familiar words beyond 400 ms, i.e., between 450 and 600 ms. In this time window the rare words elicited a broader negativity than familiar words over left-sided electrodes (i.e., F3, C3) and Cz. It is possible that this wave is a precursor of the N400, peaking later than in adults (Friedrich & Friederici, 2005) and attaining greater amplitude for rare words which, even in the absence of contextual cues, require more semantic search. This was not a main effect, however, which is consistent with Friedrich & Friederici (2005), who report that reliable N400 modulations are first observed at 14 months. In summary, the onset of word form recognition is robust at 11 months in English but the first neurophysiological signs of word recognition can be seen already at 10 months, and no clear signs of lexical-semantic activity are yet identified at 12 months.

Welsh infants

Overall we tested 79 Welsh infants. A total of 74 infants (14 9-, 12 10-, 27 11-, and 21 12-month-olds) completed the HT test successfully and were included in the final analysis. A total of 52 infants (13 9-, 13 10-, 13 11-, and 13 12-month-olds) completed the ERP test successfully and had a sufficient number of artefact free trials to be included in the final analysis.

In HT we found no significant effect of familiarity in any of the age groups (see Fig 5). Mean looking times to familiar words were nevertheless marginally longer at 11 and 12 months ($p<.096$ and $p<.071$, respectively).

Figure 5 about here

The pattern of results seen in ERPs was again consistent overall with the HT results (Fig. 6). No main effect of familiarity was found in any of the age groups, whether we looked at the N2 or the N4 windows (Fig. 7). At 11 months, however, we found signs of the familiarity effect in the form of a localised N2 amplitude difference at electrode AF4 ($p<0.05$ uncorrected) and a difference in the N4 range at electrodes AF4 and Cz (both $p<0.05$, uncorrected). The absence of a main effect in Welsh infants in both HT and ERPs and in both 11- and 12-month-olds suggests that the differentiation between familiar and rare is less efficient in Welsh than in English.

Close examination of the N2 amplitude pattern at electrode AF4 (Fig 7a) shows that the N2 amplitudes elicited by *rare words* tend to closely follow the pattern of N2 amplitudes elicited by *familiar words* (an effect not seen in English infants). It is therefore possible that in Welsh automatic orientation of attention is elicited not only by familiar words but also by rare words. The lack of a familiarity effect could then be seen as reflecting not a lack of interest (or a failure of those words to elicit a sense of familiarity) but rather a more balanced attentional response to both familiar and rare words.

Figure 6 and 7about here

A number of possible explanations could be invoked to explain the absence of a familiarity effect in Welsh infants at 11 months. It is important to note, first, the difference in sample sizes between Welsh and English. Even in North-Wales, a region in which Welsh is still in common use everyday, monolingual Welsh infants (i.e. infants exposed to more than 80% Welsh at home) are rare compared to English monolinguals. Consequently, we were able to test only 13 infants in each of the Welsh groups. In adults, a group of 12 to 15 individuals constitutes a good sample to identify amplitude and latency differences of the same order of magnitude as behavioural effects. In infants, however, the considerable extent of baseline noise means that more participants and many more trials per condition are required in order to achieve the same level of confidence as can routinely be obtained with adults.

Other explanations relate to the nature of the Welsh language itself. First, although Welsh, like English, is considered to be primarily trochaic (strong-weak accentual pattern), the accent in Welsh is manifested differently: The vowel of the first (accented) syllable is short, the medial consonant is lengthened, and the vowel of the final syllable is also long (Vihman, Nakai & DePaolis, 2006). Thus the second part of a word is more salient than the first part – the reverse of English, in which stress has the effect of lengthening the first syllable as well as adding both intensity and a pitch change. As a consequence, the first part of the word is more salient in English. Differences in accentuation have been shown to play a role in word form recognition: A change to the first consonant blocks it in English but not in French, while the reverse is true of the medial consonant in a disyllable (Vihman et al., 2004). Welsh infants could be expected to rely more on later parts of a word, as French children do, despite the classification of most Welsh disyllables as 'trochaic'. Since ERPs are time-locked to the word onset, ERP modulations discriminating familiar from rare words will be offset in Welsh and the relative increase in amplitude of the N2/N4 will be delayed and blurred. Secondly, Welsh, like all Celtic languages, has several prevalent mutation processes, by which the initial consonant of a word changes under particular grammatical conditions (e.g., feminine *cath* 'cat' becomes *gath* when preceded by the definite article *y*, whereas masculine *car* 'car' undergoes no consonant change). Depending on their grammatical gender and other aspects of the syntactic context, then, words can take different forms[5]. As a consequence the initial consonant in Welsh words serves as a relatively less reliable lexical cue than do onset consonants in English. Word recognition in Welsh thus appears to require more

[5] Of the familiar words used in the study about 75% were subject to mutation, and so will likely have been regularly heard by our infant participants both with and without the initial consonant of the base form we used, within sentential contexts. However, as noted earlier (n. 1), infants at this age do not readily 'segment' or identify familiar words within a longer discourse without specific training. Consequently the familiar words will in most cases have been heard as isolated words or in short phrases; this means that, more realistically, the form of about one third of the words will have been registered by our infant participants both with and without the onset consonants of the base forms used as stimuli.

attention to later parts of the phonotactic string, possibly delaying and blurring any familiarity effect.

Finally, it is worth bearing in mind the sociolinguistic situation of Welsh as a minority language in North Wales: Welsh speakers are also generally fluent in English while English speakers in the same community are frequently not bilingual. We will return to this issue after considering our findings with bilingual infants.

Welsh-English bilingual infants

Because bilingualism is so prevalent in North-Wales it was natural to test a sample of bilingual infants alongside our two monolingual groups; since the numbers are small, however, we tested only at 11 months, the age at which word form recognition has been found most consistently[6]. Using as the criterion for bilingual status exposure to more than 20% but less than 80% of either language in the home we were able to test 28 11-month-old infants. Any infant whose exposure to the two languages fell outside of these boundaries was included in the monolingual studies described previously. Of the infants categorised as bilingual 20 provided usable data in HT and 16 had a sufficient number of artefact-free trials (i.e., > 30) to be included in the final ERP analysis.

The stimuli in this study were different from those used in the monolingual experiments because infants had to be tested in both of their languages, which greatly increased experimental time. For HT the infants were tested on both the English and the Welsh stimuli. In the ERP procedure we used 30 familiar words (selected from the 33 used in HT) pseudo-randomly inter-mixed with 90 rare words of similar phonotactic structure. This experiment therefore conformed to a fairly standard oddball paradigm with 25% familiar and 75% rare words (unlike the 50-50 ratio used in the monolingual study). We made this choice to reduce the number of trials needed in each language, given the goal of testing infants in their two languages. All words were produced in both English and Welsh by a single highly proficient bilingual female speaker with no detectable accent in either of the two languages. Words from the two languages were presented in two different blocks.

In HT, we found significantly longer looks to English familiar words and a marginally significant difference in Welsh (Fig 8). In ERPs, we found significant N2 modulation for both English and Welsh (Fig. 9). We also found a main effect of familiarity in the N4 time window.

Figure 8 and 9 about here

Indeed, there was a main effect of familiarity on mean ERP amplitude between 180 and 310 ms and between 360 and 490 ms after word onset. There was, however, no main effect of language on the amplitude of the N2 and N4 peaks and no interaction between familiarity and language. In addition, both the N2 and N4 peaked later in Welsh (276 and 560 ms, respectively) than in English (228 and 477 ms,

[6] Welsh-English bilingual infants formed an opportunity sample constructed across the span of the 3-year monolingual project described in the “English infants” and “Welsh infants” sections of this chapter.

respectively) as indicated by a main effect of language on N2 and N4 latencies. Here again there seems to be good agreement between the behavioural data derived from HT and the neurophysiological data derived from ERPs. It is striking that a word form recognition effect is found in both languages, in both procedures, for bilinguals but not for Welsh monolinguals from the same community. We will consider the implications of this unexpected finding below.

General Discussion

We have presented the findings of our studies of infant word form recognition using HT and ERPs in parallel. In the cross-sectional study with English infants we have replicated and extended the earlier finding of the emergence of word form recognition at 11 months, using a somewhat more difficult experimental procedure (33 rather than 11 familiar word stimuli); as in the earlier HT study of Vihman et al., 2004, we found no effect at 9 months and we established further that 10-month-olds do not yet show the effect in HT. We have also now shown that the first generalised neurophysiological sign of word form recognition is found at 10 months in English, even though the first behavioural response can be detected only at 11 months. Furthermore, we were able to show the gradual developmental emergence of the N2 and N4 familiarity effects, the latter offset by one month. In addition, we have shown that by 12 months the familiarity effect vanishes in English, probably for one reason in HT (a lack of interest in decontextualised words) and another in ERPs (balanced proportion of familiar and rare words cancelling the oddball effect underlying the MMN). In Welsh infants we failed to see clear familiarity effects in either procedure, although signs of N2 and N4 modulations were found within the expected time window at the predicted electrode sites. Finally, we reported results from Welsh-English bilingual infants, showing an effect of familiarity in both English and Welsh and in both HT and ERPs. The components affected by word familiarity tended to be delayed in Welsh as compared to English. In the discussion below we address the two main ‘surprises’ presented by these studies: The absence of a word form familiarity effect in infants addressed only in Welsh in the home and the unique pattern of familiarity effects in infants addressed in both English and Welsh.

The absence of a main familiarity effect in Welsh

In agreement with a previous study we failed to find an HT familiarity effect in 11-month-old Welsh infants. However, given the fact that we found a main effect of familiarity on N2 mean amplitudes in English 10-month-olds, we expected to find an N2 modulation in Welsh at 11 months, i.e., a precursor of the behaviourally measurable familiarity effect expected at 12 months. However, neither the N2 ERP effect at 11 months nor the HT familiarity effect at 12 months were found in infants being raised with monolingual exposure to Welsh in the home (but it is worth bearing in mind the fact that the use of 33 stimuli in this study made the HT experiment relatively more difficult, resulting in smaller effect sizes in both languages at 11 months). Close observation of the pattern of N2 amplitudes at electrode AF4 (Figs. 4a and 7a) makes for an interesting comparison: Whereas the pattern of N2 amplitude in response to familiar words was very similar between the two languages and across age groups, the pattern of N2 elicited by rare words was radically different. In English, N2 amplitudes tended to be large and stable (at least for ages 9, 10 and 11 months), while N2 amplitudes for familiar words tended to become more negative with age (up to 11 months). In the case of Welsh, however, N2 amplitudes elicited by rare words closely followed the general pattern elicited by familiar words, as if rare words induced almost as much processing as familiar words. Although this provides no clear explanation as to what the difference underlying the response of infants exposed only to English or to Welsh in the home may be, this observation highlights fundamental differences in the way rare words are processed in the two languages.

It is likely that the difference is related to the imbalance in use of the two languages in the community of North-Wales. Despite the fact that the two counties of Anglesey and Gwynedd, from which our participants are drawn, boast the largest proportion of Welsh speakers anywhere in the world[7], all of the 'monolingual Welsh' infants must be regularly exposed to some English in the home (through television, radio, and visitors) as well as in the community (through overheard conversations in shops and other public places; see Gathercole & Thomas, 2005; Deuchar, 2005). This situation of dual language exposure does not obtain for English infants, most of whose parents do not know Welsh. A consequence of heavy exposure to a language in which the infant is seldom if ever directly addressed may be the requirement of a secondary level of discrimination for the minority language monolingual infants: Not only do they need to tease apart familiar from rare word forms; they also need to distinguish Welsh from English, without the kind of consistent opportunity to hear and thus gain familiarity with English that obtains for infants being raised as bilinguals.

The familiarity effect in bilinguals

Does learning English induce 'neo-familiarity' in Welsh? In other words, is the bilingual infant more sensitive to the onset consonant in Welsh words, because the onset is important in English words? Might the strong bilingual N4 response to English at 11 months be amplified by the same infants' N4 response to Welsh? All the characteristics of the monolingual responses to Welsh and English can be seen in the bilinguals. It is notable that bilingual 11-month-olds show a pattern that falls in between those observed in the English and Welsh monolinguals. Furthermore, there seems to be no cost for the on-line processing of English: the N2 peaks at roughly the same time in bilinguals and monolinguals[8]. It appears that developing a system compatible with the phonotactic structure and accentual pattern of both English and Welsh supports word form recognition in both languages, since the overt HT response is obtained for both English and Welsh in bilinguals whereas 11 month-old Welsh infants fail to show it.

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[7] In the 2001 census 76% of adults in Gwynedd and 70% in Anglesey reported an ability to read, write, speak or understand Welsh. However, all of these adults are also fluent in English, which is the dominant language for many of them.

[8] Since different paradigms were used for testing monolingual and bilingual infants, direct comparison of N2 latencies between groups is not statistically feasible. In both the English and the Welsh monolingual infants the N2 peaked at 228 ms and in the Welsh-English bilingual infants the N2 peaked at 222 ms in English and 276 ms in Welsh.

It must be kept in mind, however, that the paradigm used in the bilingual study involved a 'true' oddball paradigm since the familiar/rare ratio in words was 1:3. Since there were only 25% familiar words in total, the familiar condition was more likely to elicit not only an MMN-like response but also a P300-like response. Some authors have speculated that the P300 may be inverted in infants and peak later (i.e., between 400 and 700 ms, see Thierry, 2005). Therefore the significant N4 effect that we obtained might have been facilitated by a paradigm prone to inducing a P3 modulation. Such a hypothesis depends on making the assumption that infants were 'overtly conscious' of the low local probability of familiar words in the experiment, since the P300 is observed only when the participant is aware of the oddball context. The N2 modulation, on the other hand, might have been more pronounced due to the low local probability of familiar words. However, in retrospect, with only 30 familiar words in each of two blocks, each testing recognition in one language, it is quite surprising that the N2 effect has emerged as significant. Indeed, if only half of the familiar words included were recognized by the infants as familiar, say, the N2 modulation will have been induced by only 15 trials. A replication of this study using a balanced number of familiar and rare words will be needed to allow direct comparison with the pattern of results found in monolinguals. In any case, it is not plausible to interpret the significant N2/N4 effect as a sign of greater vocabulary size in the bilinguals, as bilingual children are known to have smaller lexicons (in each of their languages taken separately) than their monolingual peers (Pearson, 1998).

The N2 and N4 peak latency difference between English and Welsh in bilingual infants suggests that English recognition effects are observed systematically earlier in the time-course of the underlying neural events. This effect very likely relates to the prosodic and morphophonological characteristics of Welsh mentioned earlier with regards to the ERPs obtained from Welsh monolinguals: the accentual pattern, which lends less salience to the initial consonant than does English (Vihman et al., 2006) and the pervasive mutation system, which greatly lessens the cue validity of the onset consonant. An HT familiarity effect has been found in French and English at the same age, despite the fact that the initial consonant is demonstrably less salient in French than in English, for prosodic reasons (Vihman et al., 2004). Testing French monolingual infants using ERPs with the same word recognition paradigm as reported above would therefore provide an ideal way to test the relative importance of accentual pattern in delaying the N4 in the bilingual infants.

Conclusion

Our results establish the age of onset of implicit word form recognition in English at 10 months, followed by behaviourally measurable effects one month later. We also demonstrate that the developmental course of word form recognition is not universal but is, instead, highly dependent upon the characteristics of the language(s) of exposure as well as the sociolinguistic context in which learning takes place. The complementary nature of HT and ERPs is clearly evident throughout this chapter even though the actual underlying neural mechanisms of either remains to be understood. We believe that combining traditional behavioural methods and neurophysiological techniques can provide fundamentally new insight into the mechanisms of language development in terms of both the cognitive processes involved and their neural time-course.

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Figure Legends

Figure 1

Event-related potentials recorded at 7 electrodes in 11-month-old English infants exposed to familiar (black line) and rare words (grey line). The N2 window in which a main effect of familiarity was found is framed.

Figure 2

Summary of the HT results in English.

Figure 3

ERPs elicited by familiar (black wave) and rare (grey wave) words at electrode AF4. Peak labels in parentheses indicate peaks that were significantly affected by familiarity at electrode AF4 and not across the scalp. Peak labels without parentheses indicate the peaks that were affected by a main effect of familiarity across the scalp.

Figure 4

N2 familiarity effects in English infants. a. Mean amplitudes of the N2 peak at electrodes AF3 and AF4 (electrodes of maximal sensitivity) in the familiar (back bars) and rare (grey bars) conditions. b. Mean N2 amplitude difference between familiar and rare conditions at electrodes AF3 and AF4 (electrodes of maximal sensitivity).

Figure 5

Summary of the HT results in Welsh.

Figure 6

ERPs elicited by familiar (black wave) and rare (grey wave) words at electrode AF4. The amplitude of the peaks labelled in parentheses was significantly affected at AF4 but not elsewhere.

Figure 7

N2 familiarity effects in Welsh infants. a. Mean amplitudes of the N2 peak at electrodes AF3 and AF4 (electrode of maximal sensitivity) in the familiar (back bars) and rare (grey bars) conditions. b. Mean N2 amplitude difference between familiar and rare conditions at electrodes AF3 and AF4 (electrodes of maximal sensitivity).

Figure 8

HT results of 11-month-old Welsh-English bilingual infants.

Figure 9

ERP results of 11-month-old Welsh-English bilingual infants.