

# Familiar words capture the attention of 11-month-olds in less than 250 ms

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The capacity of human infants to discriminate contrasting speech sounds specializes to the native language by the end of the first year of life, when the first signs of word recognition have also been found, using behavioural measures. The extent of voluntary attentional involvement in such word recognition has not been explored, however, nor do we know what its neural time-course may be. Here we demonstrate that 11-month-old children shift

their attention automatically to familiar words within 250 ms of presentation onset by measuring event-related potentials elicited by familiar and unfamiliar words. A significant modulation of the first negative peak (N200), known to index implicit change detection in adults, was induced by word familiarity in the infants. *NeuroReport* 14:2307–2310 © 2003 Lippincott Williams & Wilkins.

**Key words:** 11-month-old infants; Development; Event-related potentials; Language acquisition; N200; Mismatch Negativity; MMN; Word recognition

## INTRODUCTION

Human infants are able to discriminate contrasting speech sounds within weeks after birth [1–3]. This discrimination capacity begins to specialize to the native language within the first year of life [4]. By the end of the first year, the first signs of word recognition can be found using behavioural methods such as the headturn paradigm. In such studies, infants are exposed to lists of words that are assumed to be familiar or rare, according to parental ratings. It is now established that 11-month-old French and English infants attend longer to lists of familiar words than to lists of rare words [5,6].

Although this is good evidence that 11-month-olds do recognize familiar word forms outside of any situational context, it is not possible to determine from behavioural measures whether the infants' response is a voluntary one or whether head turns are triggered automatically and involuntarily. Specifically, the temporal scale of behavioural responses such as head turns (measured in seconds) does not allow the neural time-course of word recognition to be addressed. In the present study, we presented 11-month-olds with familiar and rare words while recording their electroencephalogram in order to characterize the effect of familiarity on event-related potentials (ERPs) and obtain high resolution temporal measures. We assumed that familiar and rare words would elicit different ERPs reflecting specific underlying neural processes. More precisely, the particular ERP components affected by word familiarity would allow the time course of word recognition to be estimated and would shed new light on the attentional involvement of 11-month-olds listening to spoken words.

## MATERIALS AND METHODS

**Participants:** Sixteen healthy infants with normal hearing, born to monolingual British English speaking families, were tested within 1 week of their 11-month birthday. The accompanying parents were paid for their participation and gave informed consent to take part in the experiment, which was approved by the local ethics committee.

**Stimuli:** Stimuli were recordings of 56 monosyllabic (mean duration  $481 \pm 80$  ms) and 60 disyllabic (mean duration  $524 \pm 93$  ms) English words naturally produced by two women in child-directed speech register (i.e. with somewhat exaggerated prosody) and digitized for computerized presentation. Words were selected based on responses from 26 parents of 11-month-olds living in North-Wales to the Oxford Communicative Development Inventory (CDI [7]). Half of the words were judged to be familiar to the infants and half were rare English words (unfamiliar) matched to the familiar words in phonotactic structure (Table 1).

**Procedure:** Infants were seated on a parent's lap, their heads covered with a soft cap fitted with 11 electrodes. Infants were entertained in silence in a soundproofed room by an experimenter and the parent, using books, puppets, and other toys; they were free to move and vocalize at will. Stimuli were delivered through a set of four loudspeakers placed around the infant, with a minimum inter-stimulus interval of 1500 ms. Delivery was manually triggered when the electroencephalogram was stable and no obvious movements/vocalizations were being produced (this pro-

**Table 1.** Comparison of the syllable structure of words used as stimuli.

Shape	Number of monosyllables		Number of disyllables		
	Familiar	Rare	Shape	Familiar	Rare
CV(V)	5	4	CVVC	1	1
CV(V)C	17	16	CVCVC	3	6
CVCC(C)	3	5	VCV(V)C	3	3
CCVV	1	1	CV(V)CV(V)	16	11
CCVC(C)	2	2	CVCC(C)V	2	2
			CV(V)C(C)V(V)C	3	5
			CCVCC(C)VC(C)	2	2

The figures indicate the total number of words with the phonotactic shape indicated at the left. C, consonant; V, vowel; (V) and (C) refer to the inclusion in the totals of words with an additional vowel or consonant in the indicated position, resulting in diphthongs or clusters, respectively.

cedure minimizes data loss due to movement artefacts). Each word was presented twice during the experiment, once in each voice and in each of the two blocks of 116 stimuli. The order of presentation was fully randomized, so that the familiarity of any given word could not be predicted on the basis of the current word. Thus any significant difference in the ERPs elicited by familiar and rare words would indicate that the two types of words had been discriminated by the infants.

**ERP recording:** Scalp voltages were recorded from 11 Ag/AgCl electrodes applied in anatomical reference to the canthomeathal line and referenced to the left mastoid. Impedances were kept < 14 K $\Omega$ . The middle frontal polar electrode was the ground. Electrodes were located at left and right frontal sites (F3, F4), left, middle and right central sites (C3, Cz, C4), left and right parietal occipital sites (PO3, PO4) and over the right mastoid. A frontal polar electrode (FP1) was used to monitor eye movements. Voltages were filtered online bandpass between 0.1 and 100 Hz and continuously digitized at 1 kHz.

**ERP processing:** Recordings were digitally (zero phase shift) re-filtered band pass between 1 Hz (12 db/Oct) and 30 Hz (48 db/Oct), visually inspected for motor/eye artefacts, re-referenced to the left and right mastoid channels and cut into 1100 ms epochs starting 100 ms before stimulus onset. Remaining artefacts were rejected automatically when voltage amplitude exceeded  $\pm 100 \mu\text{V}$ . Data from two infants with < 30 artefact-free trials were rejected. Data from the remaining 16 infants were baseline corrected in reference to the pre-stimulus activity and averaged in each experimental condition ( $45 \pm 8$  trials per condition on average).

**Statistical analysis:** Peak detection was performed automatically in search intervals derived from the global average of the 7 recording electrodes: 90–170 ms for P1, 170–240 ms for N2, 240–350 ms for P3 and 350–480 ms for N4. Peak amplitudes and latencies were then analyzed over 6 electrodes using a  $2 \times 2 \times 2 \times 3$  repeated measures analysis of variance (ANOVA) with familiarity (2 levels, familiar/rare), word length (2 levels, monosyllable/disyllable), hemisphere (2 levels, left/right) and region (3 levels, frontal,

central and parietal occipital) as factors. A second analysis consisted of a  $2 \times 2 \times 7$  repeated measures ANOVA performed every millisecond to estimate the exact onset and offset of significant differences between experimental conditions [8]. Factors were familiarity (2 levels), word length (2 levels) and electrode (7 levels). Both analyses included a Greenhouse–Geisser correction for non-sphericity where applicable.

Interactions involving region/electrode factors were controlled using vector normalized amplitudes [9]. Unstable effects found to be significant ( $p < 0.05$ ) for < 30 consecutive measures (30 ms) were removed [10].

## RESULTS

Inspection of the mean global field power recorded from the seven measuring electrodes allowed four main components to be identified (Table 2). The first positive deviation, P1, peaking  $\sim 130$  ms after stimulus onset, was insensitive to word familiarity. On the other hand, the next negative deflection, N2, peaking at 210 ms on average, showed a significant sensitivity to word familiarity ( $F(1,15) = 5.72$ ;  $p < 0.05$ ) across all channels (Fig. 1). This effect extended into the window of the second positive peak (P3), peaking 290 ms after stimulus onset ( $F(1,15) = 7.19$ ;  $p < 0.05$ ). In addition, the N2/P3 complex was more negative over the right hemisphere than the left (N2:  $F(1,15) = 5.66$ ,  $p < 0.05$ ; P3:  $F(1,15) = 6.19$ ,  $p < 0.05$ ). By the time of the next negative peak (N4  $\sim 420$  ms), differences due to word familiarity were no longer present. Apart from significant interactions between hemisphere and region (electrode effects), no other effects were found in the peak amplitude analysis.

Repeated measures ANOVAs were performed every millisecond to estimate the exact onset and offset of differences between experimental conditions. Word familiarity induced the first significant differences 170 ms after stimulus onset (Fig. 2a,b). These differences remained significant until 248 ms after stimulus onset. To check that this effect of familiarity could not be due to spurious differences between lists of words, a random block test was performed in which ERP trials were arbitrarily grouped, independent of their familiarity ratings. As expected, we found that amplitude differences were cancelled across random groups of trials, although the main components relating to general auditory processing of spoken words remained clearly visible (Fig. 2c).

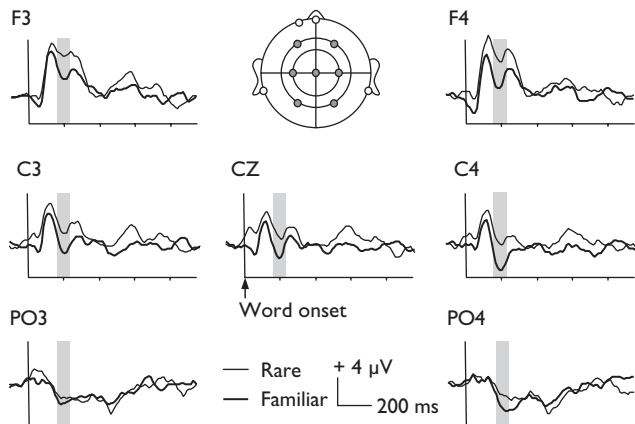
Differences between mono- and disyllabic words were in evidence only from 380 ms and lasted for about 120 ms (Fig. 2a). The effect was at first induced by word length alone (word length by electrode interaction); familiarity then entered in, resulting in a three-way interaction between familiarity, word length and electrode. The familiarity effect was greater for disyllables than monosyllables at frontal electrodes (F3 and F4). Despite the small difference in total duration between monosyllables and disyllables ( $\sim 43$  ms), word familiarity tended to induce differences during the processing of the second syllable of disyllabic words.

## DISCUSSION

The sequence of peaks that we observed can be compared with that found for 12-month-olds processing harmonic

**Table 2.** Mean ( $\pm$  s.d.) amplitudes and latencies of the 4 main ERP peaks in the four experimental conditions.

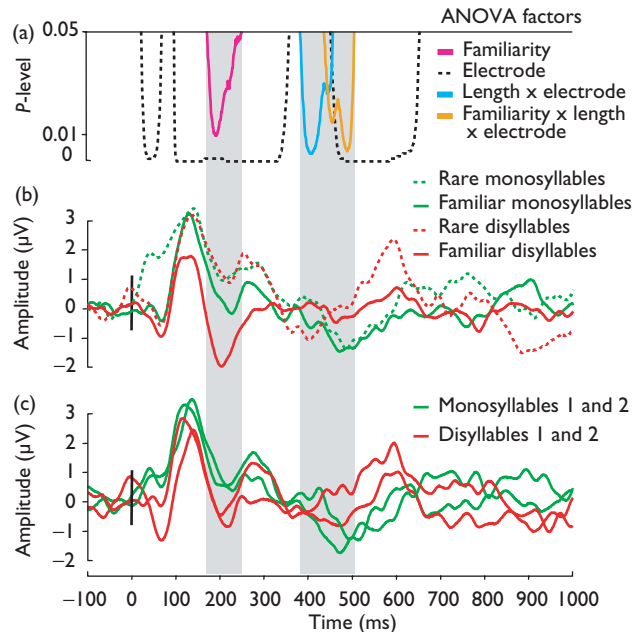
	PI	N2	P3	N4
Amplitudes ( $\mu$ V)				
Familiar disyllables	3.39 $\pm$ 3.05	-2.82 $\pm$ 4.25	1.53 $\pm$ 3.60	-2.50 $\pm$ 2.64
Familiar monosyllables	4.31 $\pm$ 3.19	-0.54 $\pm$ 2.64	2.32 $\pm$ 2.65	-2.70 $\pm$ 3.95
Rare disyllables	4.59 $\pm$ 3.22	0.30 $\pm$ 4.92	3.43 $\pm$ 3.66	-2.47 $\pm$ 2.48
Rare monosyllables	4.53 $\pm$ 2.80	-0.06 $\pm$ 4.09	3.50 $\pm$ 3.70	-2.78 $\pm$ 4.27
Latencies (ms)				
Familiar disyllables	126 $\pm$ 29	209 $\pm$ 24	291 $\pm$ 36	418 $\pm$ 51
Familiar monosyllables	135 $\pm$ 22	204 $\pm$ 25	288 $\pm$ 33	431 $\pm$ 53
Rare disyllables	132 $\pm$ 27	217 $\pm$ 21	288 $\pm$ 37	412 $\pm$ 43
Rare monosyllables	131 $\pm$ 28	211 $\pm$ 24	288 $\pm$ 40	431 $\pm$ 54



**Fig. 1.** Grand-averaged ERPs elicited by rare and familiar words at the 7 recording electrodes (F3, F4, C3, CZ, C4, PO3, and PO4). The familiarity main effect was significant from 170 to 248 ms i.e. over the N2/P3 complex (shaded period).

tones i.e. P150, N250, P350, and N450 [11]. Although the functional significance of these peaks and their relation to ERP peaks observed in adults remain a subject for speculation, the modulation of the infant N2 to auditory input variations is a well established effect thought to be automatic and involuntary, from 0 to 12 months and into adulthood [12].

In human adults, implicit involvement of attention in auditory discrimination has been linked with a modulation of the N200 ERP component, called mismatch negativity (MMN [13]). Using the oddball paradigm, in which sequences of identical stimuli (standards) are interrupted by stimuli of different duration, pitch or volume (deviants), the MMN has been repeatedly observed in infants during the first year of life [3,11,12]. It is now established that the MMN indexes automatic change detection in a wide variety of auditory stimuli, including harmonic tones [12,14], phonemes and syllables [2,3,15]. Remarkably, despite the equal probability of occurrence of familiar and rare words in the design of the present experiment, familiar words elicited a negative modulation of the N200 component, which is strikingly similar to the MMN effect. It must be borne in mind that no one infant is likely to recognize all of the familiar words included in the study so that, strictly speaking, the familiar to rare word ratio is likely to be highly skewed for the individual infant. Our results thus allow us to infer that infant attention is automatically



**Fig. 2.** ANOVA performed every millisecond, grand-average ERPs obtained in the four experimental conditions and random split analysis. (a) The familiarity effect was significant between 170 ms and 248 ms. The electrode effect was significant between 22 and 69 ms, 95 and 357 ms, and 451 and 652 ms, respectively. Length and electrode factors interacted between 381 and 456 ms. In addition, there was a significant familiarity  $\times$  length  $\times$  electrode interaction between 437 and 505 ms. (b) ERPs elicited in all four conditions (familiar and rare monosyllables and familiar and rare disyllables) are averaged from all seven electrodes. The Familiarity main effect identified in the ANOVA coincided exactly with the manifestation of the N2 peak and the onset of the P3 peak. The length  $\times$  electrode interaction indicated a period when the processing of disyllables began to differ from that of monosyllables at frontal electrodes F3 and F4. This interaction then changed into a familiarity  $\times$  length  $\times$  electrode interaction: rare and familiar monosyllables no longer elicited different voltages at this point whereas rare and familiar disyllable ERPs differed again at frontal electrodes. Beyond this point, no effect other than electrode was significant. (c) Grand-average ERPs elicited by four groups of words randomly selected from monosyllables (group 1 and 2) and disyllables (group 1 and 2). The main ERP peaks (PI, N2, P3, N4) were still visible but all differential amplitude effects across groups had disappeared.

captured  $<$  250 ms after onset by words to which they are regularly exposed in the home, but not by words which they are unlikely to have heard previously.

A question which arises here is the amount of time (or the number of phonemes) needed to identify familiar words,

based on the extent of overlap of word onsets between the rare and the familiar words. On inspection, we find that across familiar and unfamiliar word lists well over half of the rare words (72%) share an onset phoneme with familiar words. In contrast, only 36% of the initial diphones are shared between rare and familiar words. Finally, only three words share their three initial phonemes (5%). This strongly suggests that the differential response of babies is based on the first two or three phonemes, which would account for the speed with which infants were able to respond to familiar word forms.

Our result, give an interpretational framework to the outcome of the headturn procedures which have tested infant behavioural responses to speech [16]. Both English and French 11-month-olds maintain longer head turns in response to familiar words than to unfamiliar words [5,6]. The widespread use of the term preference in this connection, with its suggestion of a voluntary behaviour, may not be appropriate; instead, the infants appear to be producing a wholly involuntary response.

Importantly, the amplitudes measured in the course of the N2/P3 complex were more negative on right-sided electrodes than on their left counterparts (Fig. 1). This result is congruent with N2 modulations observed in 20-month-olds [17] and 13- to 17-month-olds [18]. Such a lateralized effect supports the theory of early right-hemisphere involvement in language development [18] but stands in contrast to studies of phoneme discrimination, which have found early signs of left-greater-than-right asymmetries [1]. While left temporal brain structures are thought to be more involved in phonological decoding and phonological discrimination in both infants [1,19,20] and adults [15,21,22], it has been proposed that word-level recognition processes involve right-sided regions during the earliest stages of language acquisition [18,23,24].

## CONCLUSION

The ability of familiar words to elicit a shift of attention in 11-month-olds has been seen in behavioural experiments for some time [5,6]. Electrophysiology makes it possible to track the neural time-course of these processes and to formulate hypotheses as to the nature of the attentional shifts observed in infants. Insofar as ERP differences are confined to MMN-like modulations, it may be assumed that the engagement of attention by familiar words in 11-month-olds is an automatic process which starts very early in the course of auditory processing, i.e. within 250 ms. Further studies will be necessary to determine the developmental onset of word form recognition as well as the onset of semantic processing, which can be expected to occur some weeks or months later.

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