International Journal of Psychophysiology 96 (2015) 84–94

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

# Feature-specific transition from positive mismatch response to mismatch negativity in early infancy: Mismatch responses to vowels and initial consonants

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ARTICLE INFO

*Article history:*
Received 4 December 2014
Received in revised form 28 February 2015
Accepted 18 March 2015
Available online 24 March 2015

*Keywords:*
MMN
P-MMR
Infants
Speech perception
ERPs
Phonological saliency

ABSTRACT

This study investigated how phonological saliency, deviance size, and maturation affect mismatch responses (MMRs) in early infancy. MMRs to Mandarin vowels and initial consonants were measured using a multi-deviant oddball paradigm in adults, newborns, and 6-month-olds. The vowel condition consisted of Mandarin syllable *da* as the standard, *du* as the large deviant and *di* as small deviant. As for initial consonant condition, we took syllable *ba* as standard, *ga* as large deviant, and ba as small deviant. While adults showed typical mismatch negativities (MMNs), newborns demonstrated broad positive MMRs (P-MMRs) to both initial consonants and vowels. For 6-month-olds, deviance size affected the polarity of MMRs to vowels. The large deviant *du*/*da* contrast elicited an adult-like MMN, while the small deviant *di*/*da* contrast elicited a P-MMR. Initial consonant changes elicited only P-MMRs, regardless of deviance size. In summary, MMRs to vowels switched from P-MMR at birth to MMN at 6 months. However, the polarity transition was not found for MMRs to initial consonants. The developmental trajectories of MMRs to vowels and initial consonants further support the phonological saliency hypothesis.



## 1. Introduction

Both behavioral and electrophysiological studies have shown that infants are born with the universal capacity for discriminating phonetic contrasts, although phonetic perception becomes attuned to their native language during the first year of life (Cheour et al., 1998b; Kuhl et al., 1992; Polka and Werker, 1994; Rivera-Gaxiola et al., 2005; Werker and Tees, 1984). Sensitivity to native phonetic contrasts increases, while that to non-native ones declines. The change to language-specific phonetic perception has been found at 6 months of age for vowels (Kuhl et al., 1992; Polka and Werker, 1994) and between 8 and 10 months for consonants (Kuhl et al., 2006; Werker and Tees, 1984). Phonetic perception in infancy is correlated with later language development (Kuhl et al., 2005; Tsao et al., 2004), which suggests that perceptual learning provides a foundation for later and more abstract language learning (Werker and Yeung, 2005). Furthermore, a growing body of longitudinal studies has shown that newborns' electrophysiological responses to speech sounds predicts their pre-reading language skills between 2.5 and 6.5 years of age (Guttorm et al., 2005, 2010; Molfese and Molfese, 1985, 1997) and reading abilities at 8 years of age (Molfese, 2000). These findings suggest that phonological processing ability in early childhood could be a building block for language and reading acquisition. However, few studies have addressed how the maturation timetable of auditory change-related cortical responses varies between vowels and consonants in a specific language.

The mismatch negativity (MMN) is an event-related potential (ERP) component for auditory change detection. The MMN is typically obtained using a passive oddball paradigm and indexes change detection based on a sound representation constructed of repeated auditory input. In adults, the MMN is observed as a frontal-distributed negativity peaking between 100 and 250 ms after stimulus onset by subtracting the ERPs for the standard stimuli from those for the deviant stimuli (Näätänen et al., 1978, 2007). MMN amplitude increases, whereas peak latency decreases, as the discriminability of the standard and deviant sounds rises (Näätänen et al., 2007; Sams et al., 1985). It is thought to reveal whether listeners have formed sufficient representation of automatic pre-attentive discrimination (Näätänen et al., 2011; Winkler,

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http://dx.doi.org/10.1016/j.ijpsycho.2015.03.007
0167-8760/

2007). Furthermore, the MMN is sensitive to long-term memory traces built on language experience. Cross-linguistic studies have reported enhanced MMN responses to native linguistic contrasts in comparison to MMN responses to non-native contrasts among children younger than 1 year old (Cheour et al., 1998b; Friederici et al., 2007). Most importantly, the MMN can be elicited even when a participant does not attend to the stimuli (e.g., reading a book or watching a silent movie). Thus, it serves as an excellent tool for assessing auditory discrimination, especially for infants and children with limited attention or motivation.

Although the MMN is well established in adults, the polarity and latency of mismatch responses (MMRs) in infants are highly inconsistent across studies. Alho et al. (1990) first reported an MMN peaking between 160 and 400 ms after pure tone changes from 1000 to 1200 Hz among sleeping newborns. Studies have also reported the infant MMN to pitch changes (Cheour et al., 2002a, 2002b), duration changes (Brannon et al., 2004, 2008), and phonetic changes (Cheour-Luhtanen et al., 1995; Cheour et al., 1998a; Kushnerenko et al., 2001; Martynova et al., 2003). However, the infant MMN usually persists for a longer interval in a relatively late time window. Other studies have reported a positive MMR (P-MMR), rather than an MMN, to various speech and non-speech changes between 200 and 400 ms, mainly at a younger age (Dehaene-Lambertz and Baillet, 1998; Dehaene-Lambertz and Dehaene, 1994; Friederici et al., 2002; Jing and Benasich, 2006; Leppänen et al., 1997; Morr et al., 2002; Novitski et al., 2007). For example, Leppänen et al. (1997) observed a P-MMR peaking between 250 ms and 350 ms to pitch change of pure tones in newborns. Friederici et al. (2002) reported that 2-month-old infants demonstrated a P-MMR peaking at approximately 400 ms to vowel duration changes in syllables. Dehaene-Lambertz and Dehaene (1994) reported that change in initial consonants elicited a frontal-distributed positivity peaking at approximately 390 ms in 3-month-old infants. This response was suggested to index a neural network present from birth for extracting the phonetic category, notwithstanding irrelevant acoustic variations (Dehaene-Lambertz and Baillet, 1998; Dehaene-Lambertz and Pena, 2001).

However, the determining factors for the polarity of MMRs remain unclear. Given that the P-MMR has been primarily found in newborns and young infants, neural maturation is hypothesized to account for the polarity change of MMRs (Cheng et al., 2013; He et al., 2007; Kushnerenko et al., 2007; Trainor et al., 2001a, 2003). Trainor and colleagues tried to identify the polarity of MMRs at the individual level. They observed that the proportion of P-MMR-responding participants decreased, whereas the proportion of MMN-responding participants increased between 2 and 6 months of age when detecting temporal changes (Trainor et al., 2001b, 2003). He et al. (2007) reported a polarity shift from slow P-MMR to MMN between 2 and 4 months in response to pitch changes of piano tone. A longitudinal study of MMRs to pitch change detection among a group of infants from birth to 12 months showed that adult-like MMNs stabilize between 3 and 6 months of age (Kushnerenko et al., 2002). Cheng et al. (2013) collected MMRs to changes in Mandarin lexical tone longitudinally, reporting a P-MMR to lexical tone changes (tone 1 vs. tone 3) at birth, but an MMN to the same contrast at 6 months. These studies suggest that the polarity change of the MMR emerges before 6 months for both speech and non-speech sounds. In general, the adult-like MMN gradually becomes prominent, while the P-MMR diminishes with age. These observations imply that neural maturation may play a role in the transition of MMR polarity from positive to negative.

In addition to neural maturation, stimulus-related factors, such as shorter inter-stimulus interval (ISI) and smaller size of deviance, which may decrease the discriminability between standard and deviant stimuli, have been found to affect the polarity of MMRs (Ahmmed et al., 2008; Maurer et al., 2003b; Morr et al., 2002). For example, Morr et al. (2002) reported that although adult-like MMNs to large deviance (1000 Hz vs. 2000 Hz) were reliably present in 2- to 7-month-old infants, the majority of infants failed to show adult-like MMNs to small deviance (1000 Hz vs. 1200 Hz) until 4 years of age. Maurer et al. (2003b) used substantially smaller frequency (1000 Hz vs. 1060 or 1030 Hz) and phoneme ("ba" vs. "ta" or "da") deviance, with shorter intervals relative to those in most previous studies. They reported that 6- to 7-year-old children revealed P-MMRs to all these contrasts, while adults showed typical frontal-central MMNs. Ahmmed et al. (2008) used a 1000-Hz tones with 2%, 5%, and 10% (1020, 1050, 1100 Hz) deviance at ISIs of 200 ms or 400 ms. Typical developing 7- to 11-year-old children showed P-MMRs to the 2% contrast at an ISI of 400 ms but required at least 5% deviance to elicit an MMN. In sum, the discriminability between standard and deviant stimuli may also affect the presence of the P-MMR.

Mandarin is a tonal language, in which a syllable possesses four possible elements: lexical tones, initial consonants (onset), vowels, and syllable-final consonants. Among these four elements, only lexical tones and vowels are compulsory units for a Mandarin syllable. Studies of speech production among 2- to 6-year-old children showed that the four elements are acquired with different developmental sequences (Cheung, 2000; Cheung and Hsu, 2000; Li and Tompson, 1977a; Lin et al., 2008). Children made few errors in producing lexical tones by 2 years old, and tones 1 and 4 were acquired prior to tones 2 and 3 (Li and Tompson, 1977b). Children aged between 1;6 (year;month) and 2;0 could produce all of the single vowels (Cheung, 2000), whereas all vowels, including diphthongs and triphthongs, were mastered by 3 years (Lin et al., 2008). The initial consonants were acquired last, and not all initial consonants achieved 75% of accuracy criteria until 6 years (Cheung and Hsu, 2000; Lin et al., 2008). Hua and Dodd (2000) proposed a phonological saliency hypothesis to account for the order of Mandarin phonological acquisition. The phonological saliency of a syllable element was determined by the following factors: (a) the status of a component in the syllable structure, particularly whether it is compulsory or optional; (b) the capacity of a component to differentiate the lexical meaning of a syllable; and (c) the number of permissible choices within a component in a syllable structure. Accordingly, lexical tones have the highest saliency in Mandarin, as they are compulsory for a syllable, and there are only four alternative choices. Vowels, compared to lexical tones, have a relatively large number of permissible choices (9 single vowels, 9 diphthongs, and 4 triphthongs); therefore, vowels have a lower saliency than lexical tones. Initial consonants, which include 21 choices and represent an optional element for a Mandarin syllable, have the lowest saliency. The phonological saliency hypothesis was generally supported by speech production data in typically and atypically developing Mandarin-speaking children. The more salient element is acquired earlier than the less salient one, and furthermore, atypically developing children mostly made initial consonant errors, but seldom made tonal and vowel errors (Hua, 2009; Hua and Dodd, 2000). Lee et al. (2012) examined the phonological saliency hypothesis by investigating the MMRs to Mandarin lexical tone, vowel, and initial consonant contrasts in 4- to 6-year-old preschoolers. For both compulsory elements of Mandarin—lexical tones and vowels—the large deviants elicited MMNs, whereas the small deviants elicited P-MMRs. However, for the optional element—the initial consonants—only the P-MMR was found, regardless of the size of the deviance. However, in this study, no polarity change in MMRs was found between 4 and 6 years old. Cheng et al. (2013) reported that MMRs to the large deviant lexical tone contrast switched from a P-MMR in newborns to an MMN in 6-month-olds, suggesting that maturation of lexical tone perception emerges before 6 months of age. According to the phonological saliency hypothesis, the polarity transition of MMRs to vowels should be evident in early infancy, similar to the transition for lexical tone, whereas the transition for initial consonants should not appear until late childhood. Further studies are required to investigate the developmental trajectory of vowel and initial consonant perception in early infancy.

In summary, previous studies on preschoolers have shown that MMRs to vowels are more mature than MMRs to initial consonants