

Does production facilitate discrimination? An infant mismatch negativity study

Isabelle Edström¹, Lisa Gustavsson², Petter Kallionen², Marie Markelius^{1,2}, Andrea Strandberg¹, Nina Strömberg¹ & Katarina Svensson¹

¹Department of Clinical Science, Intervention and Technology, Karolinska Institute, Stockholm

²Department of Linguistics, Stockholm University, Stockholm

Abstract

MMN is an ERP component that reflects pre-attentive discrimination between a recurring standard sound and a deviating sound. MMN is frequently used in infant studies focused on speech development since its elicitation does not require the attention of the child. The general ability of infants to discriminate speech sounds is gradually specialized towards discrimination of phonetic contrasts in their mother tongue. The aim of the present study was to examine if an MMN response is elicited by naturally varying speech stimuli (/ti/ and /ki/) and if this response is stronger for the speech sound that infants typically produce at this age (/t/). An EEG experiment with an oddball paradigm was designed. Participants were 19 infants (9-mo). An MMN-like negative response to deviants compared to standards was found, however it was not statistically significant. No significant interaction effect was found for MMN and type of deviant stimulus. Variation in the standard stimuli may have contributed to the lack of effect. It is also possible that the infants already were equally competent in discriminating both speech sounds, which may account for the small difference between the deviant waveforms.

Introduction

Mismatch negativity (MMN: Näätänen, Gaillard & Mäntysalo, 1978) is an ERP-component frequently studied with EEG-recordings. MMN is elicited by discriminable changes in an otherwise uniform stream of stimuli (Näätänen, Gaillard & Mäntysalo, 1978) and is usually studied in oddball paradigms (first used by Squires, Squires & Hillyard, 1975). The auditory MMN response is elicited by changes in frequency or amplitude for sinusoidal sounds (Sams et al., 1985; Ford & Hillyard, 1981) and to changes in complex sounds, such as speech sounds (Pakarinen et al., 2013). The MMN response is the result of a comparison process in the brain, between a memory trace formed by the

recurring stimuli and a deviating sound (Näätänen, 1990). For adults, the MMN latency is typically 100–200 ms (Näätänen, Gaillard & Mäntysalo, 1978, 1978; Näätänen & Alho, 1997) whereas it is longer in infants (250–450 ms) (Cheour et al., 1998; Conboy & Kuhl, 2011). Its distribution is generally strongest at fronto-central sites (Čeponiene et al., 2004).

MMN is particularly appropriate for infant studies considering it is elicited by unattended stimuli (Näätänen, 1991), in comparison to other behavioural methods such as head turning techniques and high-amplitude-sucking.

Late difference negativity (LDN) is another ERP component that has been linked to sound change processing in MMN studies (Čeponiene et al., 2004; Alho et al., 1992), with a peak latency of 350–500 ms (Korpilahti et al., 2001).

Typical speech development in children follows a certain pattern where dental and bilabial sounds (e.g. /t/, /d/, /b/ and /p/) are produced early. Velar speech sounds (e.g. /k/ and /g/) are typically produced later (e.g. Locke, 1983; Lohmander, Olsson & Flynn, 2011; McCune & Vihman, 2001). Newborns' competence to discriminate phonetic contrasts of their mother tongue improves during their first year at the cost of a more general ability to discriminate phonetic contrasts from virtually any language (Kuhl et al., 2006). EEG studies have revealed that the MMN response to non-native speech sounds is attenuated and the response to native speech sounds increases by the time the infant is 12 months old (Cheour et al., 1998).

The present study will focus on 9-month-old infants' discriminatory ability by measuring MMN in response to naturally produced speech sounds. The aim of the study is to see if there is an auditory MMN elicited in response to dental and velar consonants respectively and further to examine whether there is a difference between the MMN waveform for the two deviating stimuli. It is plausible that the MMN response would be stronger for when the dental consonant serves as a deviant, considering

9-month-old infants typically can produce dental sounds. The idea would be that production facilitates discrimination.

Method

Participants

The participants were 19 healthy infants (10 female; $m=9$ months, 14 days; $sd=9.16$ days). All participants' mother tongue was Swedish and four came from bilingual homes (Italian, Finnish, Japanese, and Serbian).

Letters with information about the study were sent to 200 randomly selected families accessed from the National Swedish address register, based on the infant's date of birth (pre-term infants were not excluded). Informed consent was obtained from all caregivers and the study was conducted with the approval of the local ethical committee (Dnr 2011/955-31/1). The participants received a diploma for their participation.

Stimuli and experimental design

The Swedish CV syllables /ti/ and /ki/ were pronounced by a native Swedish speaking female and recorded in an anechoic chamber. The syllables were produced in a standard sentence (*Jag sa /x/ till de andra*) multiple times with deliberately varied stress patterns in order to acquire naturally varying speech sounds. The speech sounds were manually edited in Wavesurfer (ver. 8.4.2.9) and 18 stimuli were chosen for the experiment (9 /ti/; 9 /ki/). An oddball paradigm design was used with two blocks of stimuli. The speech sound /ti/ served as standard ($p = 80\%$) and /ki/ as deviant stimuli ($p = 20\%$) in one of the blocks (dev/ki/). /ki/ served as standard ($p = 80\%$) and /ti/ as deviant ($p = 20\%$) in the other block (dev/ti/). The order in which the blocks were presented was randomized for every subject, with an interstimulus interval (ISI) of 600 ms. The deviant stimuli occurred at pseudorandom order but was always preceded by at least two standard stimuli. Each block was initiated with 12 standard stimuli and consisted of 60 deviant and 240 standard stimuli. The total length of the experiment is 12.4 min.

Procedure

The participants were seated in the caregivers' lap on a chair placed approximately 70 cm from a computer screen in a sound-attenuated room. A children's TV-program (In The Night Garden, BBC) was used as a source of

distraction during the experiment. Loudspeakers (NuForce S-1) were placed on each side of the screen, through which the auditory stimuli was presented at approximately 60–70 dBA. E-Prime 2.0 was used to run the experiment.

A HydroCel Geodesic Sensor Net (128 channels) was used. During recording vertex reference was used and impedance was held below 50k Ω for most channels. EGI hardware and software (Electrical Geodesics, Inc.) were used during recording.

Processing of data

Analysis of data was performed with Net Station 4.2, using a bandpass filter set to 1–40 Hz (FRI). Epochs of 800 ms including a 200 ms pre-stimulus period were separately averaged for the standards and deviants respectively. Segments and channels were rejected when exceeding 200 μ V in the relevant channels and data was re-referenced to mastoids. The mean voltage of the pre-stimulus (200 ms) period served as baseline. A grand average file was created for all subjects, after omitting four participants due to noisy data.

Based on visual inspection a time-window of 150–300 ms was chosen. The MMN parameters were computed from the difference waveform by subtracting the grand average standard-stimulus ERP from the grand average deviant-stimulus ERP.

Statistical analysis

A multivariate ANOVA (2×2 , repeated measures) was performed on the average data for the frontal electrode Fz (11), with the variables deviant stimuli, standard stimuli and the two blocks (dev/ti/, dev/ki/), respectively.

Results

The deviant stimuli elicited an MMN response (peak 150–300 ms), and a later negativity at 500–600 ms, measured at electrode Fz (see *Figure 1*). Another early ERP that was elicited (peak 80–100 ms) can be seen for the average waveform for the deviant stimuli, as seen in *Figure 1*. There is a small observable difference in the average waveform depending on block type (dev/ki/ vs. dev/ti/) at 150–300 ms, measured at electrode Fz, as seen in *Figure 2*.

The ANOVA (2×2) showed an insignificant MMN effect ($F_{1,14} = 2.615$, $p < 0.05$, ns.), and an insignificant interaction between the two blocks ($F_{1,14} = 0.171$, $p < 0.05$, ns.), see *Figure 3*.

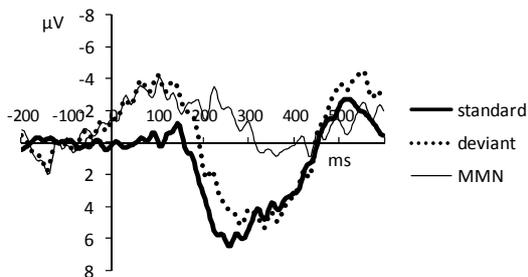


Figure 1. Auditory ERPs measured at frontal (Fz). The average waveform to the standard stimuli (thick line), deviant stimuli (dotted line), and the MMN shown as a difference wave (thin line). The time window is one epoch (800 ms).

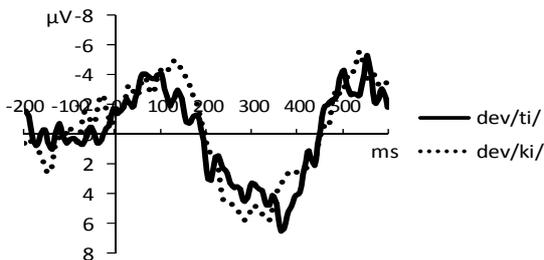


Figure 2. Auditory ERPs measured at frontal (Fz). The average waveform to the deviant stimuli from the blocks dev/ti/ (thick line) and dev/ki/ (dotted line). The time window is one epoch (800 ms).

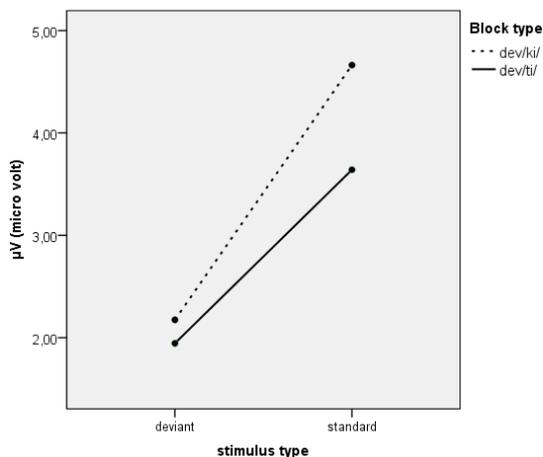


Figure 3. There is an observable difference in amplitude (μV) depending on stimulus type (standard vs. deviant) for both blocks, however not statistically significant. There was no observable interaction effect between MMN and block type.

Discussion

The aim of the present study was to examine the discriminatory ability for dental and velar sounds in 9-month-old infants. The primary purpose was to see if an MMN response was

elicited for the speech sounds /ti/ and /ki/. The results indicate a negativity similar to the MMN component, with a latency of 150–300 ms. However, the ANOVA indicated no significant effect of stimulus type (standard vs. deviant). The insignificant result might be related to the fact that the number of participants was relatively low as well as some of them being omitted due to noisy data. A prerequisite of MMN elicitation is that a memory trace of the standard stimuli has been formed. It is likely that this neural representation is weaker when using varying complex sounds, as was the case in this study. Furthermore, previous studies have suggested that MMN amplitude is higher for tone stimuli than for more complex linguistic stimuli (Korpilahti et al., 2001). Nevertheless, it is of importance to study the MMN response to naturally produced speech sounds with varying characteristics since it is more applicable to non-experimental contexts.

Moreover, this study aimed to analyse whether there is a difference in amplitude between the two waveforms elicited by the deviant stimuli. The results showed no significant interaction effect with MMN. The average waveform representing the block dev/ti/ is slightly more negative, for the time window 150–300 ms. Even if this is in line with the hypothesis of the study, the results are not significant, and hence cannot confirm it. The infant's native language specialization during its first 12 months results in a greater competence in discriminating mother tongue contrasts (Cheour et al., 1998). The infants in this study are 9 months old, and it is plausible that, contrary to our hypothesis, they are already equally competent in discriminating the two speech sounds /t/ and /k/.

Due to the participants' young age, movement artefacts were difficult to avoid completely, which is the case in any infant study.

The negativity with a 500–600 latency of has the characteristics of the ERP-component LDN, which has been suggested to reflect automatic stimulus change detection, primarily in children, (Alho et al., 1992), however the function of LDN is still unclear. Other studies have suggested that the LDN reflects a later stage in sound processing (Čeponiene et al., 2004). This response however has not been further statistically analysed in this study. The early negative component with a peak around 80–100 ms is apparent in the deviant

but not the standard waveform. This response has previously been related to the neuronal refractory period, not associated with the MMN (Walker et al., 2001).

Studying infants' discriminatory ability by measuring MMN provides interesting insights in language development. Variation in the speech stimuli is essential when studying phonetic contrasts rather than acoustic differences. Possibly the present study pushed this variability too far.

References

- Alho, K., D.L. Woods, A. Algazi & R. Näätänen. 1992. Intermodal selective attention. II. Effects of attentional load on processing of auditory and visual stimuli. *Electroencephalography and Clinical Neurophysiology* 82:356–368.
- Čeponiene, R., T. Lepistö, M. Soininen, E. Aronen, P. Alku & R. Näätänen. 2004. Event-related potentials associated with discrimination versus novelty detection in children. *Psychophysiology* 41:130–141.
- Cheour, M., R. Čeponiene, A. Lehtokoski, A. Luuk, J. Allik, K. Alho & R. Näätänen. 1998. Development of language-specific phoneme representations in the infant brain. *Nature Neuroscience* 1(5): 351–353.
- Conboy, B. T. & P. K. Kuhl. 2011. Impact of second-language experience in infancy: brain measures of first- and second-language speech perception. *Developmental Science* 14(2):242–248.
- Ford, J.M. & S.A. Hillyard. 1981. Event-related potentials (ERPs) to interruptions of a steady rhythm. *Psychophysiology* 18(3):322–330.
- Korpilahti, P., C. M. Krause, I. Holopainen & A. H. Lang. 2001. Early and Late Mismatch Negativity Elicited by Words and Speech-Like Stimuli in Children. *Brain and Language* 76:332–339.
- Kuhl, P., E. Stevens, A. Hayashi, T. Deguchi, S. Kiritani & P. Iverson. 2006. Infants show a facilitation effect for native language phonetic perception between 6 and 12 months. *Developmental Science* 9(2):F13–F21.
- Locke, J. 1983. *Phonological acquisition and change*. New York: Academic Press. (With a foreword by Michael Studdert-Kennedy.)
- Lohmander, A., M. Olsson & T. Flynn. 2011. Early consonant production in Swedish infants with and without unilateral cleft lip and palate and two-stage palatal repair. *Cleft Palate–Craniofacial Journal* 48(3): 271–285.
- McCune, L. & M. M. Vihman. 2001. Early phonetic and lexical development: a productivity approach. *Journal of Speech, Language, and Hearing Research* 44:670–684.
- Näätänen, R. 1991. Mismatch negativity outside strong attentional focus: a commentary on Woldorff et al. *Psychophysiology* 28(4):478–484.
- Näätänen, R. 1990. The role of attention in auditory information processing as revealed by event-related potentials and other brain measures of cognitive function. *Behavioral and Brain Sciences* 13:201–288.
- Näätänen, R. & K. Alho. 1997. Mismatch negativity—the measure for central sound representation accuracy. *Audiology & Neurootology* 2(5):341–353.
- Näätänen, R., A. W. K. Gaillard & S. Mäntysalo. 1978. Early selective-attention effect on evoked potential reinterpreted. *Acta Psychologica* 42(4):313–329.
- Pakarinen S., T. Teinonen, A. Shestakova, M.S. Kwon, T. Kujala, H. Hämäläinen, R. Näätänen, M. Huotilainen. 2013. Fast parametric evaluation of central speech-sound processing with mismatch negativity (MMN). *International Journal of Psychophysiology* 87(1):103–110.
- Sams, M., P. Paavilainen, K. Alho & R. Näätänen. 1985. Auditory frequency discrimination and event-related potentials. *Electroencephalography and Clinical Neurophysiology* 62(6):437–448.
- Squires, N.K., K.C. Squires & S.A. Hillyard. 1975. Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. *Electroencephalography and Clinical Neurophysiology* 38 (4):387–401.
- Walker, L.J., M. Carpenter, C.R. Downs, J.L. Cranford, A. Stuart, D. Pravica. 2001. Possible neuronal refractory or recovery artifacts associated with recording the mismatch negativity response. *Journal of the American Academy of Audiology*. 12(7):348–356.

Proceedings of Fonetik 2013

The XXVIth Annual Phonetics Meeting
12–13 June 2013, Linköping University
Linköping, Sweden

Studies in Language and Culture
no. 21

Robert Eklund, editor



Linköping University

Conference website: www.liu.se/ikk/fonetik2013

Proceedings also available at: <http://roberteklund.info/conferences/fonetik2013>

Cover design and photographs by Robert Eklund

Photo of Claes-Christian Elert taken by Eva Strangert on the occasion of his 80th birthday

Proceedings of Fonetik 2013, the XXVIth Swedish Phonetics Conference

held at Linköping University, 12–13 June 2013

Studies in Language and Culture, no. 21

Editor: Robert Eklund

Department of Culture and Communication

Linköping University

SE-581 83 Linköping, Sweden

ISBN 978-91-7519-582-7

eISBN 978-91-7519-579-7

ISSN 1403-2570

© The Authors and the Department of Culture and Communication, Linköping University, Sweden

Printed by LiU-Tryck, Linköping, Sweden, 2013