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Phonetic training and non-native speech perception — New memory traces evolve in just three days as indexed by the mismatch negativity (MMN) and behavioural measures

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ABSTRACT

Language-specific, automatically responding memory traces form the basis for speech sound perception and new neural representations can also evolve for non-native speech categories. The aim of this study was to find out how a three-day phonetic listen-and-repeat training affects speech perception, and whether it generates new memory traces. We used behavioural identification, goodness rating, discrimination, and reaction time tasks together with mismatch negativity (MMN) brain response registrations to determine the training effects on native Finnish speakers. We trained the subjects the voicing contrast in fricative sounds. Fricatives are not differentiated by voicing in Finnish, i.e., voiced fricatives do not belong to the Finnish phonological system. Therefore, they are extremely hard for Finns to learn. However, only after three days of training, the native Finnish subjects had learned to perceive the distinction. The results show striking changes in the MMN response; it was significantly larger on the second day after two training sessions. Also, the majority of the behavioural indicators showed improvement during training. Identification altered after four sessions of training and discrimination and reaction times improved throughout training. These results suggest remarkable language-learning effects both at the perceptual and pre-attentive neural level as a result of brief listen-and-repeat training in adult participants.

1. Introduction

Automatically responding language-specific memory traces (Näätänen et al., 1997) are the basis for speech sound perception. Categorical perception and the ability to discriminate between different speech sounds are also crucial for speech perception, discrimination being easier at the category boundary area and harder within the category (Liberman et al., 1957). Native language speech sound representations and categories evolve already in early childhood (Cheour et al., 1998), but new neural representations can also develop for non-native speech categories, e.g., in an authentic environment in the case of immigrants (Winkler et al., 1999), in classroom learning (Peltola and Aaltonen, 2005; Peltola et al., 2012), and in early immersion (Peltola et al., 2005). At least in the beginning of the learning process, second language is perceived through mother tongue categories, which makes foreign language learning particularly demanding. This difficulty may be explained through the Native Language Magnet effect (NLM) (Kuhl, 1991) which describes how the prototypical representatives of phoneme categories hinder discrimination near them and facilitate across category discrimination. Native speech sound categories and their prototypes may be located so that a non-native language category boundary is positioned at that same place as the prototype or in its immediate vicinity. A situation like this would cause problems for a language learner, since the native language prototype region would quite probably cause discrimination problems in perception and thus result also in production difficulties.

Neural mechanisms of auditory learning can be studied with the mismatch negativity (MMN) response, a component of the event-related potential. It is an excellent tool for investigating memory traces and speech perception at the pre-attentive level. MMN is automatically elicited by infrequent, or deviant, stimuli among frequent, or standard, stimuli. MMN reflects discrimination accuracy and its amplitude is

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connected to discrimination results. It also reflects plastic changes caused by learning (for a thorough review on the MMN see e.g., Kujala and Näätänen, 2010). The MMN responses to native language contrasts are larger in amplitude and earlier in latency than those for foreign language contrasts, which are irrelevant in the mother tongue, as shown by Näätänen et al. (1997) in their research where MMN responses were elicited for Finns and Estonians for their mother tongue contrasts but not for Finns for the foreign Estonian contrast. Winkler et al. (1999) similarly showed MMN responses to a Finnish contrast in Finns but not in naïve Hungarians, but they also showed responses to the Finnish contrast in Hungarians fluent in Finnish. Speech discrimination studies often combine behavioural tests with psychophysiological measures and, for example, in Näätänen et al. (1997), the identification result nicely showed a lack of a category in the area of the Estonian vowel /õ/ for Finns while, of course, there was one for the Estonians. The study by Winkler et al. (1999) showed consistent results in the reaction times and the MMN. However, if the acoustic differences between the stimuli are vast, the influence of the native language disappears (Peltola et al., 2003). On the other hand, second language learning may lead to native-like responses (e.g., Peltola and Aaltonen, 2005; Peltola et al., 2012; Winkler et al., 1999).

Neural plastic changes take place when we learn or train to perceive something new. Training induced MMN can be elicited for frequency differences in general (e.g., Näätänen et al., 1993; Menning et al., 2000; Atienza and Cantero, 2001; Kujala et al., 2001b). More importantly, training effects have been shown in studies using linguistic stimuli (e.g., Kraus et al., 1995; Tremblay et al., 1997, 1998; Menning et al., 2002; Tremblay and Kraus, 2002). Many of these studies have used some type of discrimination training (Näätänen et al., 1993; Kraus et al., 1995; Menning et al., 2000; Atienza and Cantero, 2001) or identification training (Tremblay et al., 1997, 1998). For example, one week discrimination training with synthetic speech stimuli varying in voice onset time (VOT) altered the neurophysiologic responses in the study by Kraus et al. (1995). In that study a same-different two-alternative forced-choice discrimination with visual feedback was used and there were six 1-hour training sessions between the pre- and post-training testing. Similarly, Tremblay et al. (1997) showed results in a nine day identification training study with synthesised speech stimuli varying in VOT. Visual feedback was used also in this study. The effects were seen in MMN duration and area increment as well as in discrimination and identification scores. Moreover, the training effects transferred to untrained stimuli with a different place of articulation, which was seen in the decreased onset latency of the MMN. The changes were observed after nine 20 min sessions of training in five days; pre- and post-training testing took two days each (Tremblay et al., 1997). In another study Tremblay et al. (1998) showed that changes resulting from VOT identification training with visual feedback can be seen in neural activity before behavioural learning. The training effects in a period of ten days were seen by the fourth day in the MMN, however, the occurrence of the behavioural changes was individual and the changes were seen either on the same day as in the MMN or during the following days (Tremblay et al., 1998). Also Menning et al. (2002) showed an increase in the behavioural performance together with an increase in the amplitude of the Mismatch Negativity Field (MMF) when the German participants were trained Japanese mora-timing. Forced-choice, two-alternative, self-adjusting staircase method discrimination training took place during ten consecutive workdays for approximately 1.5 h per day. Here, as well, visual feedback was given. Reaction times improved rapidly, already in the first session, whereas the MEG was recorded only before and after the training sessions and hence, the results were seen after 10 days. To sum up, these training studies using speech stimuli trained subjects with identification or discrimination methods. The training periods were 7–10 days consisting of several sessions (4–10) lasting approximately 20 min minimum to 1.5 h maximum per day (one study did not report the session time). Feedback was given in all studies. Training was executed either between pre- and post-testing or mixed with testing. Training effects were found in each study. All in all, it is fair to conclude that laboratory training can lead to learning, or more specifically, to "robust, linguistically-functional learning" (Bradlow, 2008, p. 299), even in difficult learning settings.

The goal of the present study was to determine how a listen-and-repeat training of foreign language words — or more precisely, a feature which is phonologically relevant in the foreign language but not in the mother tongue — affects neural and perceptual plasticity. In other words, the aim was to see how the listen-and-repeat training affects the formation of new memory traces and the perception of foreign language items. In order to study this, we measured the MMN response. We also used behavioural tests to determine whether the category boundary, goodness of the category exemplars, discrimination sensitivity, and reaction time are simultaneously affected by the same training.

Our training stimuli were two synthesised English words which pair up as a minimal pair — '*feel*' /fi:l/ and '*veal*' /vi:l/ — differing only in VOT in the first labiodental fricative phoneme segment, the former being voiceless and the latter voiced. There is no such distinction in Finnish, and only the unvoiced /f/ phoneme is present in its sound system. In addition, Finnish uses no acoustic cue of voicing in any contrast, so the distinction is based on a totally new parameter. As both the English /f/ and /v/ assimilate to the Finnish /f/ — though unequally (/f/ better than /v/) — according to the Perceptual Assimilation Model (PAM) (Best and Strange, 1992), the discrimination of these sounds is expected to cause difficulties. Finns perceive the English /v/ as a poor representative of the Finnish /f/ and not as a representative of a different category. Also, according to the Speech Learning Model (SLM) (Flege, 1987), second language sounds which are similar, not identical or new, to native categories are to cause severe difficulties. Hence, the English /v/ is problematic for a Finnish learner who now has to perceive this voicing difference; the English /v/ is neither identical (in which case there would not be any problems) nor is it totally new (in which case there would be intermediate difficulties) to a Finnish language learner. What makes the situation even more difficult, is the fact that Finnish has a voiced labiodental approximant /ʋ/ which differs from the English /v/ by the manner of articulation. The Finnish orthography is transparent and nearly phonemic, so in writing, these two phonemes (Finnish /ʋ/ and English /v/) are represented by the same grapheme <v> and, because of this, Finnish learners of English quite often use the Finnish approximant sound instead of the correct fricative one. The transparent Finnish orthography links certain kinds of acoustics to a particular grapheme, but in this case the grapheme <v> contains acoustic properties completely alien to Finns (Peltola, 2004). On the other hand, seeing words like '*feel*' and '*veal*' written as two different words, may provide some help, for example, in a categorisation task. Nevertheless, the contrast is difficult for Finns (naïve and English learners) since when Finnish is considered, they are not required to perceive voicing concerning fricatives, whereas the opposite is true in the case of the English language (see Bradlow (2008) for a similar comparison of Japanese and English).

The main difference in our study, compared to many training studies, is that our subjects trained with an articulatory listen-and-repeat training (a similar method is widely used in schools at foreign language classes, but it may also be combined with feedback), and this training took just a few minutes per day during only three consecutive days. In addition, in this study we provided no feedback, the amount of training was notably small and the participants were tested and trained every day. Perception of the unfamiliar voicing contrast is hypothesised to be challenging before training. In other words, /v/ is part of the category /f/ for Finns and thus the English /f/–/v/ category boundary is within the acoustic area of the Finnish /f/ prototype. It can be hypothesised that before training this is reflected in many ways: in the identification test the /v/ category should be smaller than /f/ and in the goodness rating it should be rarely rated as a good category representative; discrimination may be harder and slower, and the MMN response may be very small. However, it is expected that our training has some effects resulting in