The Connectivity of Musical Aptitude and Foreign Language Learning Skills:

Neural and Behavioural Evidence

by Riia Milovanov

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Abstract

Given the structural and acoustical similarities between speech and music, and possible overlapping cerebral structures in speech and music processing, a possible relationship between musical aptitude and linguistic abilities, especially in terms of second language pronunciation skills, was investigated**.** Moreover, the laterality effect of the mother tongue was examined with both adults and children by means of dichotic listening scores. Finally, two event-related potential studies sought to reveal whether children with advanced second language pronunciation skills and higher general musical aptitude differed from children with less-advanced pronunciation skills and less musical aptitude in accuracy when preattentively processing mistuned triads and music / speech sound durations.

The results showed a significant relationship between musical aptitude, English language pronunciation skills, chord discrimination ability, and sound-change-evoked brain activation in response to musical stimuli (durational differences and triad contrasts). Regular music practice may also have a modulatory effect on the brain's linguistic organization and cause altered hemispheric functioning in those who have regularly practised music for years. Based on the present results, it is proposed that language skills, both in production and discrimination, are interconnected with perceptual musical skills.

List of publications

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List of figures and tables

List of abbreviations

ANOVA analysis of variance
AMMA Advanced Measures of Music Audiation
CEF Common European Framework
CV consonant-vowel
DL dichotic listening
DTT Distorted Tunes Test
EEG electroencephalogram
ERP event-related potential
fMRI functional Magnetic Resonance Imaging
FL forced-left condition
FR forced-right condition
HSD honestly significant difference
ISI inter-stimulus interval
LE left ear
MBEA Montreal Battery of Evaluation of Amusia
MMN mismatch negativity
NF non-forced condition
PET positron emission tomography
P600 late positive component
RE right ear
REA right ear advantage
SEM standard error of mean
SOA stimulus onset asynchrony
WAIS Wechsler Adult Intelligence Scale
WISC III Wechsler Intelligence Scale for Children, 3rd. ed.
$\mathcal{C}^{2\%}$ mistuned modification of a C major triad (2% flat)
$\mathcal{C}^{4\%}$ mistuned modification of a C major triad (4% flat)

1. Introduction

Each sound repetition, both speech and nonspeech, develops its neural representation in the auditory cortex (Näätänen et al., 2005). Without proper neural models formed in the auditory cortex for the phonemic combinations and prosodic patterns to be pronounced, the learning of a foreign language will not reach the targeted level (e.g., Näätänen, 2001). In a similar vein, a musician needs accurate neural representations for tones in order to be able to learn to play the instrument in tune and in time. This skill is required, for example, with string instruments where the quality of the sound produced depends on the player's ability to listen and correct his/her own production. Thus, perceiving music and speech both seem to depend upon subtle and accurate auditory processing skills, enabling the correct production of an intended output.

Could music and language also share common neural resources? Possible interaction between music and speech memory systems has not been ruled out; on the contrary, there is increasing evidence, to be reviewed below, highlighting the accuracy obtained at perceiving phonetic or prosodic contrasts in native or foreign language with subjects with musical aptitude or musical training (Anvari et al., 2002; Slevc & Miyake, 2006; Magne et al., 2006).

There are common features in music and language, for example many different styles of music have a series of strict rules which in a way resemble grammar (Lerdahl & Jackendoff, 1983). In addition, pitch as indicated by staff notation, forms an equivalent of phonemes, the sounds of speech (Risset, 1991). Rhythm, as well as pitch, has an important role in language production and perception; they are part of the stress system of words and sentences (Alcock et al., 2000). Complex pitch patterns or pitch changes are used for segmenting the speech stream (Foxton et al., 2003; Jusczyk, 1999). Ross et al. (2007) analyzed a database of individually spoken English phonemes in order to examine whether musical intervals arise from the relationships of the formants in speech spectra that determine the perception of distinct vowels. The results indicated that the frequency relationships of the first two formants in vowel phonemes represent all 12 intervals of the chromatic scale. Moreover, they stated that the human preference for the chromatic scale intervals arises from experience with the way speech formants modulate laryngeal harmonics to create different phonemes.

Vocal expression or, in other words, prosody, relies on acoustic signals which transmit different kinds of messages to a listener (Juslin & Laukka, 2003). Prosody can also be described as the music of speech. According to Harmer (1991), competent users of language (who include both native and non-native speakers) know how to recognise and produce a range of sounds, know where to place the stress in words and phrases and know what different intonation tunes mean and how to use them. Magne et al. (2006) state prosody has a linguistic and emotional function and can be defined as the patterns of stress and intonation in a spoken language and, at the acoustic level, by the same parameters that define melody, namely fundamental frequency (F0), intensity, duration and spectral characteristics. Thompson et al. (2004) presented evidence that adult musicians are better in identifying emotions (happy, sad, fearful, angry) than adult nonmusicians when mediated in spoken sentences and tone sequences that mimicked the spoken sentences' prosody. To sum up, similarities between music and language cannot be ignored, and the emotional and aesthetic values both means of communication may have must be acknowledged.

Patel & Iversen (2007) announced the need to accurately assess the role of musical experience in shaping linguistic abilities in order to reveal possible pre-existing neural differences relevant for speech processing in subjects with or without musical aptitude. They suggested longitudinal studies in which groups are matched at the outset on various neural and behavioural measures of auditory processing and are tested for linguistic skills before and after musical training. The present PhD thesis aims at determining the impact of musical aptitude on foreign language acquisition, especially in terms of second language pronunciation skills in normal individuals. In foreign language teaching, correct pronunciation may be considered one of the most important skills to achieve; it is crucial for effective communication. Both behavioural and neural indices were used to illuminate the effects of practising music, and also musical aptitude, which the subjects possessed to a varying degree. The role of age and laterality are also briefly dealt with in this thesis. As will be discussed below, it is inevitable that speech and music interact not only at the cognitive level but also at the neural level. However, the existing knowledge of overlapping cerebral structures in speech and music processing is as yet somewhat ambiguous.

2. Interactions between speech and music

2.1 Neural mechanisms behind speech and music processing

2.11 Lateralization of speech and music functions

A number of studies indicate an overlap of the behavioural and neural resources between language and music. However, data supporting the separability and especially lateralization of speech and music functions in the brain hemispheres have been obtained. Lateralization implies the superior capacity of the left and right hemispheres to perform distinct sets of skilled behaviours (Geschwind & Galaburda, 1987). Evidence for this differentiation of the functions of the two hemispheres first came mainly from comparing the behaviour of patients who have had their left or right hemisphere injured to the behaviour of healthy subjects in specific tasks (for example dichotic listening, see Hugdahl et al, 1999 for an overview and Section 3.1 below) which ostensibly tap processing by one hemisphere or the other. In addition to behavioural methods, information on the specialized functions of the two hemispheres can today be obtained via the use of advanced technology, examples being functional Magnetic Resonance Imaging (fMRI), positron emission tomography (PET) scanning (both of which measure the increases in cerebral blood flow during experimental cognitive tasks) and event-related potential recordings (Peretz, 2002; Zatorre et al., 2002; Tervaniemi & Hugdahl, 2003).

The areas of the left hemisphere, in particular those known as Wernicke's and Broca's areas, have been shown to be closely associated with the comprehension and production of speech, respectively. There is a neural connection between the above-mentioned auditory and motor representations of language areas (Hickok et al., 2003; Hickok & Poeppel, 2004, 2007; Vigneau et al., 2006), which logically supports the idea of speech production including the ability to repeat heard speech (Benson et al., 1973). The left hemisphere seems to be dominant for language functions in the majority of right handed individuals (Frost et al., 1999; Vikingstad et al., 2000). The left hemisphere is often associated with creative language use, including syntactic and semantic processing and the motor operations involved in speaking and writing (for meta-analysis, see Vigneau et al., 2006). However, Maess et al. (2001) indicate that the left Broca's area is not only responsible for language syntax functions – it is also involved in the processing of musical syntax. In addition to this, temporal functions, which evidently are also essential components of music, are processed in the left auditory cortex, at least when the musical duration stimulus is considered to be rapid, 25-50ms, such as a fragment of speech (Zatorre et al., 2002; Poeppel, 2001).

There is still considerable uncertainty regarding the identification of specific neurofunctions of music (McMullen & Saffran, 2004), even if it is often generalized as being processed in the right hemisphere (Zatorre et al., 1994; 1996; Sparing et al., 2007). Patients with right hemisphere trauma are most likely to have impaired musical perception skills (Liegeois-Chauvel et al., 1998; Zatorre & Samson, 1991). Furthermore, aphasics with left hemisphere lesions often possess well-preserved musical capacities (Kaplan & Gardner, 1989). Right hemisphere dominance for music perception has been detected in healthy subjects, too (Zatorre et al., 2002). Singing, which can be a form of communication like speech, combines both linguistic and musical functions. Therefore, it is not very surprising that both right and left sided hemispherical involvement has been connected with this form of signalling (Gordon & Bogen, 1974; Brust, 1980).

The conceptualization of hemispheric specialization is not straightforward. Even though there is evidence, for example, with speech sounds that temporal acoustic properties predict the relative specialization of right and left auditory cortices' functioning, one must still bear in mind that there are also more abstract linguistically relevant properties that must be considered important. In their review article, Zatorre and Gandour (2007) request examination of the role of the interactions between afferent pathways that carry stimulus information and emphasize the role of top-down processing mechanisms that modulate these processes. They state that whenever one considers high-order or abstract knowledge, one automatically invokes memory mechanisms. Zatorre and Gandour remind the reader that any domain-specific effect is also a memory effect; linguistic status, context effects, learning or attention can modulate early sensory cortices' functioning which can therefore effect early processing via top-down effects. To sum up, top-down executive processes within auditory pathways may have an important role in explaining the perception processes of speech and music stimuli.

2.1.2 Neuroimaging and electroencephalographic studies on speech and music

Koelsch (2005) is of the view that the human brain processes music and language with overlapping cognitive mechanisms in overlapping cerebral structures. This view promotes the theory that producing music and speech sounds are connected since birth and musical elements aid learning linguistic functions such as sound patterns and meaning (Fernald, 1989) and sound patterns and syntax (Jusczyk & Krumhansl, 1993). As Masataka (2007) sums up, young infants respond strongly to music and use it as a means of communication before they are capable of producing words.

Magne et al. (2006) tested the hypothesis that musical training facilitates pitch processing not only in music but also in language. Their results show that musician children detected incongruities in both music and language better than non-musician children did. The differences between the two test groups were also seen in auditory cortex functioning: early negative components in music and late positive components in language were found in musician children while no such components were present with the non-musician children.

Other neuroimaging and electroencephalographic studies provide further evidence of the collaboration of music and language. Speech relies heavily upon sequentially organized temporal features (Jaramillo et al., 2001), and these are also relevant to music. In other words, determining where a musical or a linguistic phrase ends requires temporal skills. Moreover, semantics is a key feature of language and it has been shown as indexed by an event-related potential (ERP) study that both music and language can prime the meaning of a word, and music can, just as language, determine the physiological indices of semantic processing (Koelsch et al., 2004). Patel (1998; 2003) has suggested that processing structural incongruities in music and language elicits similar electrical potentials in the brain due to a possible overlap in the neural areas and operations responsible for structural processing.

Wong et al. (2007) examined the encoding of linguistic pitch in ten non-musicians and ten amateur musicians processing Mandarin phonemes. Their study provided evidence for the positive effect of long-term music exposure on speech, especially in terms of linguistic pitch, encoding at the brainstem. A recent study by Song et al. (2008) provides further evidence of the role of the brainstem in second language learning: their results demonstrate plasticity in the adult human auditory brainstem following short-term linguistic training.

Schön et al. (2004) compared pitch and music in language: the results indicated that adult musicians detected both variations of pitch in melodic phrases and linguistic prosody better than non-musicians. Furthermore, tonal languages (languages that exploit variations in pitch to signal meaning differences in monosyllabic words, such as Thai and Mandarin Chinese) provide a good example of the use of prosody as a linguistic function. Gandour et al. (1998) investigated by means of PET how speakers of a non-tone language (English) and Thai speakers discriminated between pitch patterns in Thai words. The results indicated that encoding of complex auditory signals is influenced by their functional role in a particular language. Another study conducted by Gandour et al. (2002) gives parallel results to Gandour et al. (1998): when Thai and native English speakers performed same/different judgments of Thai vowel durations, consonants, and hummed (non-speech) durations, the Thai group had a left-hemispheric dominant pattern of brain activation while the English group processed more bilaterally both vowel and consonant durations.

Additionally, Schön et al. (2008) showed that by means of songs second language learning was more efficient when compared to learning with speech sequences. They state that children’s songs and lullabies have an emotional function, but they can also facilitate linguistic processing. Songs can also be a powerful tool when rehabilitating stroke patients. Regular self-directed music listening during the early post-stroke stage enhanced cognitive recovery (i.e. verbal memory) in addition to preventing negative mood states (Särkämö et al., 2008).

Taken together, there is an increasing body of evidence provided by neuroimaging and electroencephalographic studies indicating that practicing music affects language skills at both the cognitive and neural level.

2.2 Musical aptitude vs. expertise

2.2.1 Musical aptitude, tests, and findings

It is assumed that most individuals acquire basic musical competence through everyday exposure to music during development (Hannon & Trainor, 2007; Trainor 2005; Trehub & Hannon, 2006). According to Hannon & Trainor (2007), everyday exposure to music enables us for example to detect wrong notes, and to tap, remember and reproduce familiar melodies. As they put it, such implicit musical knowledge does not require formal training. Explicit training, however, in their opinion seems to affect neural processes in a range of domains and modalities.

Terminological uncertainty can be sometimes confusing or even misleading in the field of musicality research. Terms, such as *musical capacity, musical talent, musical aptitude* and *musical ability* are often discussed and used as synonymously with the term *musicality,* which they actually are not. Boyle (1992) takes the position that musical capacity is the result of genotype and maturation. Musical talent, on the other hand, is recognized by the high level of musical performance. The achievements of musical ability are the results of capacity, surroundings and musical education. It is justified to say that there is no exact and unequivocal definition for the term musicality and there are as many definitions for the term as there are researchers. In this thesis, the term *musical aptitude*, which includes the traits of musical capacity and the implicit impact of the surroundings, is preferred.

Singing proficiency appears to be normally distributed in the general population with a majority of occasional singers being able to sing on time with few pitch deviations (Dalla Bella et al., 2007). As with singing proficiency, musical ability is normally distributed in the population, in other words, few have a very high musical aptitude, a similar number have a low aptitude and the majority lands in between these two ultimate ends with average proficiency (Drayna et al., 2001). According to Sloboda (1993), musicality develops over the first decade of life through normal enculturation. He is of the view that this ability can be developed to a high level with regular practice and constant engagement with musical materials. Very recently, the genetic basis of musical aptitude has been the subject of interest (Drayna et al., 2001; Ukkola et al., 2009). In this thesis, it is considered that the person's genetic composition creates the basic abilities, and the stimuli given by the environment (learning, practice, and valuation for instance) reinforce musicality. Thus, the musically talented person's ability for example to discern sounds and rhythm can be developed.

Not only can the terminology concerning musicality be vague, but also measuring musical aptitude is problematic. Musical aptitude tests have a history of over 85 years of development and refinement (Vispoel et al., 1997), and most measure discrimination skills, not production. Furthermore, the musical capacities or talents that should be measured pose a question that has been asked ever since the first test was released (the Seashore Measures of Musical Talents) in 1919. The Advanced Measures of Music Audiation test (AMMA; Gordon, 1989), the Bentley test (1966), the Montreal Battery of Evaluation of Amusia (MBEA; Peretz et al, 2003), the Karma musical aptitude test (1993) and the Distorted Tunes Test (DTT; Drayna et al, 2001) have their own criteria and ways of defining musical aptitude. For example, the Bentley test examines pitch discrimination ability, tonal memory, chord analysis, and rhythmic memory. The test developed by Seashore (1960) considers musicality to be an entity emerging from relatively independent subskills organized according to the different sound parameters and cognitive demands (e.g., pitch-discrimination accuracy/temporal accuracy, vs. memory for pitch/rhythm).

In contrast, the test developed by Karma (1993) considers musicality to be a more general ability to structure sound information cognitively into meaningful chunks. Both the above-mentioned views of musicality have been shown to have their neural counterparts. When subjects were divided into two groups on the basis of their pitch-discrimination accuracy (a test item adopted from Seashore), it was found that the "accurate" subjects had a Mismatch Negativity, MMN (see Section 3.3 for the definition of the term MMN) with smaller pitch deviations than the "less-accurate" subjects (Lang et al., 1990). Correspondingly, when Tervaniemi et al. (1997) recorded the MMN to a structural change in a sound sequence (adopted from a test item from Karma) among two groups of subjects divided on the basis of their performance in the Karma musicality test, their MMN mirrored the group difference seen in their behavioural test performance. To conclude, as seen from these data, the neural basis of both sensory and cognitive types of musical aptitudes can be revealed by neural measures. Moreover, musicality consists of several relatively independent parts which cannot actually be ranked into primary or secondary categories in importance in defining musicality.

2.2.2 Musicians vs non-musicians (both anatomical and functional findings)

Neuroimaging studies present evidence that certain brain areas differ among musicians and non-musicians. Differences have been found in the auditory cortex, motor and visuospatial areas (Gaser & Schlaug, 2003; Schneider et al., 2002). Increased cortical representation of the somatosensory areas of the left-hand fingers in string players and auditory areas in skilled musicians has been detected (Elbert et al., 1995; Pantev et al., 1998). In addition to this, musicians seem to possess a larger anterior part of the corpus callosum than non-musicians (Schlaug et al., 1995a), and absolute pitch seems to be associated with increased leftward asymmetry of cortex subserving, music-related functions (Schlaug et al., 1995b). As Magne et al. (2006) clarify, such anatomical differences have functional implications. It seems that not only the mother tongue acoustical features but also regular practising of music has neurological or even neuroanatomical consequences. The role of the age at which practising a musical instrument was initiated and its effects on brain plasticity is not studied widely, but it seems that the younger the subjects begin playing an instrument, the greater the effect on the brain (Elbert et al., 1995).

Taken together, learning the complex motor and auditory skills required in practising music can cause structural adaptations in the brain in response to long-term skill acquisition and the repetitive rehearsal of those skills (Gaser & Schlaug, 2003).

2.3. Targets and mechanisms of language learning

2.3.1 Correct pronunciation

The general curriculum set by the Finnish educational system for the study of foreign languages (Perusopetuksen opetussuunnitelman perusteet, 2004) is based on the instructions in the Common European Framework [CEF] (2001). The CEF provides a common basis for the curriculum guidelines, foreign language study materials and examinations across Europe and describes in a comprehensive way what language learners have to learn to do in order to use a language for communication and what knowledge and skills they have to develop in order to be able to act effectively. The concept of communicative competence is highly emphasized in the CEF. In other words, the students should systematically practise speaking the foreign language and become familiar with the communicative strategies of the target language. When teaching English, the instructors also need to be sure that their students can produce the various sounds that occur in the English language. Pronunciation may be considered one of the most important factors of the language; poor articulation can easily cause misunderstandings in communicative situations. Therefore, one should pay careful attention to the special characteristic features of the target language.

By comparing the two sound systems (the native language and the second language) in contact, it is possible to show where learning problems in foreign language pronunciation are likely to occur. One tends to transfer the native language characteristics into the second language, and it is the differences between the two sound systems that are more likely to cause learning problems (Lado, 1957; Wiik, 1965; Flege, 1998). Therefore, one must check whether the native and target languages have a phonetically similar phoneme and whether the variants of the phonemes are similar in both languages. It is also important to discover whether the phonemes and the variants are similarly distributed.

The differences between phonetic systems usually imply that entirely new phonemes or new uses of familiar sounds must be learnt. Using native language phonemes as acceptable substitutes for phonemes in the target language can cause problems. For instance, the distinction [s] - [ʃ] need not be made in Finnish, but in English, [s] and [ʃ] belong to separate phonemes. Therefore, the Finnish [s] cannot be used for English [ʃ], if misunderstandings are to be avoided (Dulay et al., 1982; Moisio & Valento 1976:). However, no serious learning problems should occur if a target language phoneme is in every respect fully identical to one in the native language, for example /n/ in Finnish and English. Moreover, if a native language sound is sufficiently similar to that of the target language, it can be identified by a speaker of the target language as the phoneme intended. The Finnish phoneme / l / may sound un-English, but it is still recognizable as the phoneme corresponding to English / l / (Moisio & Valento 1976). It seems that only a portion of pronunciation mistakes are due to the learner's mother tongue. Most learners make the same kind of mistakes regardless of their mother tongue (Dulay et al., 1982).

Wiik (1965) states that learning difficulties are found in those items which are not the same in the native language and the target language. Sounds that are physically similar to each other in the native and target languages are easy to learn because the native language phoneme can simply be transferred to the target language system (Lado, 1971). The differences between the sound systems which cause pronunciation difficulties can be classified in the following way (Wiik, 1965; Lehtonen, et al., 1977; Moisio & Valento 1976): *A.) Physical differences:* A physical sound or group of sounds occurs in one language but not in the other. For example, in the word *thin* the Finns tend to hear the [θ] -

phoneme often as /s/ or /f/ -phonemes. In this study, physical differences are assumed to cause both hearing and pronunciation difficulties. *B.) Relational differences:* Two physically similar sounds exist in both the mother tongue and the target language but the sounds are grouped differently into phonemes. For instance, in Finnish [v] and [w] are *allophones* but in English they are different phonemes and /w/ must be kept apart from /v/. Relational differences are assumed to cause difficulties as well. *C.) Distributional differences*: similar sounds or phonemes occur in both languages, but in different environments. For instance, in Finnish the sound /s/ does not follow the sound /t/ directly at the beginning or at the end of the word. In this present study, the distributions of phonemes are described in relation to words, not in relation to other phonemes or allophones.

In this thesis, the English pronunciation skills of Finnish subjects were determined by the RP (Received Pronunciation, Crystal, 1985) standard. The special emphasis was on the phonemes which do not belong to the Finnish sound system (see Section 3.2 for further details of the pronunciation test).

2.3.2 The role of age in second language acquisition

The role of age of acquisition of the second language, either naturally or in a classroom situation, is recognized as a predictor of second language outcomes. The starting age of acquisition is observed to significantly correlate negatively with attained second language proficiency at the end state (Birdsong 2005, 2006; De Keyser & Larson-Hall, 2005). Pronunciation seems an aspect in language known to be most difficult to learn after childhood (e.g., Larsen-Freeman & Long, 1992). On the other hand, adults may compensate for this difficulty by their high-level of motivation. There are also biographical variables other than age and motivation which may affect the outcome of the second language pronunciation. Birdsong (2006) lists psycho-social integration with the foreign language culture, aptitude with several presumed components, such as imitative ability, working memory capacity, metalinguistic awareness, learning styles and strategies (for an overview of these variables, see Dörnyei & Skehan, 2003; Doughty, 2003). Both neural and behavioural second language acquisition studies provide evidence that the younger the start, the easier it is to learn the target language phonetic system (Cheour et al., 2002) and correct pronunciation (Larsen-Freeman & Long, 1992; Halsband, 2006).

2.3.3 Second language acquisition and the brain

Studies on the cerebral organization of multiple languages hint that there is variation in cerebral activation when processing native and foreign languages. Perani et al. (1996; 1998) investigated Italian subjects with moderate knowledge of the English language listening to stories in both Italian and English. The results indicated that the cortical areas activated by the native language were not activated by the second language. They came to the conclusion that the cerebral organization of the native and second languages is shaped by the starting age of second language acquisition. Kim et al. (1996; 1997) found that adjacent but distinct brain areas were activated for native and second languages. However there were differences in brain activation patterns between early and later second language learners: the age when second language acquisition began seems to play an important role in the organization of cortex functioning.

Deheane et al. (1997) investigated French language speakers who had acquired English at school after the age of seven. Interestingly, listening to the mother tongue always activated a similar set of areas in the left temporal lobe. The second language, on the other hand, activated a highly variable network of left and also right frontal areas, individual subjects varying from complete right lateralization to standard left lateralization patterns for English. This suggests that first language acquisition relies on a dedicated left-hemispheric cerebral network, while second language learning is not necessarily dependent on a reproducible biological substrate. On the other hand, Klein et al. (1994) compared cerebral blood flow when repeating first and second language words. They presented data indicating that the left putamen is the region which plays a crucial role in both first and second language articulation.

In sum, it thus seems that age plays a crucial role in second language acquisition, especially in terms of pronunciation skills. However, while there seem to be many advantages to beginning learning the second language phonetic system at an early age, adult foreign language learners may attain a native-like accent just as well as the children. In addition, further studies are needed to clarify the first and second language cerebral representation in different age groups and levels of second language proficiency.

2.4 Music as a tool in language learning

Musical aptitude and music skills have often been connected to other cognitive skills, such as linguistic skills, cognitive development, motor abilities, social skills, and the ability to express oneself (Draper & Gayle, 1987). Several correlative studies have shown that, on average, participants with musical aptitude perform better in many fields such as general intelligence (Lynn & Gault, 1986; Lynn, Wilson & Gault, 1989; Schellenberg, 2004), verbal memory (Brandler & Rammsayer, 2003; Chan, Ho & Cheung, 1998; Ho, Cheung, & Chan, 2003), literacy (Barwick et al., 1989; Lamb & Gregory, 1993), visual perception (Brochard, Dufour & Deprés, 2004), spatial skills (Hetland, 2000) and basic auditory and visual timing skills (Rammsayer & Altenmüller, 2006).

Not only musical aptitude but practising music may also have the capacity to facilitate the learning of academic skills. There are a number of studies on how music can enhance different cognitive functions, such as language learning among healthy and especially in impaired subjects. Music provides helpful mnemonics for verbal learning, especially at early developmental stages and in learning academic skills (Calvert & Billingsley, 1998). The developmentally disabled may find a rehearsal mechanism in music for learning non-musical material (Claussen & Thaut, 1997; Gfeller, 1983). Text can be recalled more effectively when it is accompanied by music (Wallace, 1994). A classic observation in neurological studies is that aphasics can sing the words they cannot produce otherwise: Melodic Intonation Therapy has been used since the 1970s in order to train everyday phrases (such as: a cup of coffee). The phrases are intoned and tapped out in a syllable-by syllable manner (Sparks et al., 1974; Naeser & Helm-Estabrooks, 1985). There is new evidence that singing in synchrony with an auditory model is beneficial for word recalling in aphasia patients, since choral singing may entrain more than one auditory-vocal interface (Racette et al., 2006).

Music may provide a helpful means for understanding the structure of a word by setting the restricted number of syllables per beat (Rubin, 1995; Poulin-Charronat et al., 2005). Overy (2003) has examined dyslexic children who have been found to have timing difficulties in both domains – music and language. She showed that music lessons provide a valuable support tool for children with dyslexia; classroom music lessons had a positive effect on both phonologic and spelling skills. Besson et al. (2007) are of the view that difficulties in pitch processing may partly account for reading difficulties in phonological dyslexics. A combination of phonological training and audio-visual training improved the detection of strong pitch incongruities in speech in dyslexics. Interestingly, this improvement was reflected in auditory cortex functioning: only control children elicited large positive components (P600) before training. However, when the training period was over, the dyslexic group also started showing P600 components (Santos et al., 2007). It is suggested that musical training has beneficial effects on reading skills, especially with the dyslexic, and particularly when auditory skills are improved (Fujioka et al., 2006; Ho et al., 2003).

As Peterson & Thaut (2007) put it, despite the growing body of evidence that music affects cognition, the neural substrates of that influence still remain unclear. They investigated coherent frontal oscillations in the EEG while subjects heard either a spoken or sung version of the word list of Rey’s Auditory Verbal Learning Test. There were no significant changes in coherence associated with conventional verbal learning. However, verbal learning with a musical template strengthened coherent oscillations in the frontal cortical networks involved in verbal encoding.

3. Research methodologies and previous findings

3.1 Dichotic listening

Dichotic listening (DL) is a procedure used in investigating selective attention in the auditory system via a listening task. In dichotic listening, two different auditory stimuli are presented to the participant simultaneously, exactly at the same time, one to each ear, by using a set of headphones. Participants are asked to attend to one or both of the auditory stimuli and are asked what they have heard. Dichotic listening can be used to define the hemispheric asymmetry of a particular cognitive function, such as the auditory cortex processing language (Hugdahl, 1998).

Typical DL stimuli consist of presentations of pairwise combinations of (stop) consonants, such as /b/, /d/, /g/, /p/, /t/, /k/ and the vowel /a/ (Hugdahl, 1999). The typical outcome in a standard DL test is greater percentage of correct reports from the right ear when compared to the left ear. This is called Right Ear Advantage (REA), indicating that the language-dominant left hemisphere receives a stronger signal from the right ear (Figure 1).

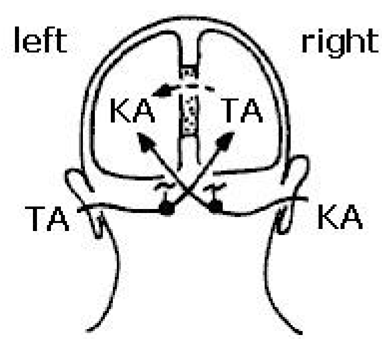


Figure 1. Dichotic listening. When two verbal stimuli (TA, KA) are presented to the left ear and to the right ear simultaneously, and both are articulated as loud, it is more likely that a healthy right-handed person will hear better the material presented to the right ear (KA) which has direct access to the language-dominant hemisphere. When the left ear receives the verbal material (TA), the material must first go to the right hemisphere and traverse the corpus callosum to get to the language-dominant left hemisphere.

DL studies with non-speech sounds have in general revealed a left ear advantage, supporting right hemisphere processing superiority for these kinds of stimuli (Hugdahl, 1999; Deouell et al. 1998; Mathiak et al., 2002). Attention may modulate a structurally-based laterality when the subject shifts attention to the right or left side of the auditory space. Usually in the DL test, for 1/3 of the DL-stimuli the subjects are given an instruction to report what they have heard and no particular directive regarding attention is given. In 1/3 of the trials, the subjects are instructed to pay attention to the right ear stimuli (forced-right condition), and in the other 1/3 of the trials, the subject's attention should be directed to the left ear (forced-left condition). In normal right-handed individuals, the REA increases during forced-right condition and age (Hugdahl, 1999; Hugdahl et al., 2001).

Hugdahl et al. (1999) compared the brain activation during dichotic presentations of consonant-vowel and musical instrument stimuli with the PET technique. The consonant-vowel syllables and musical instrument sounds activated bilateral areas in the superior temporal gyri. However, musical stimuli resulted in greater neural activation in the right hemisphere and correspondingly, speech stimuli were more left lateralized. Hashimoto et al. (2000) applied DL with the fMRI method. Their results suggested that multiple auditory and language areas (including both Wernicke's and Broca's areas) may play an essential role in integrating the functional differentiation for speech recognition.

3.2. Other behavioural methods on investigating second language discrimination and pronunciation skills

Minimal pair listening discrimination tests (i.e., two words that differ only in one phoneme (thin-Finn), and different types of pronunciation tests are traditional methods in investigating second language skills (Kirk et al., 1997). These experiments are simple to conduct, and the equipment needed is easily acquired; however, individual testing is often advisable with child subjects in order to ensure that the instructions are fully comprehended. Whether or not production follows discrimination skills has been investigated, and the following conclusions apply to Finnish speakers learning English:

Tommola (1975) presented evidence that the results from English phonemic discrimination tests do not correlate with results from productive skills; the production part of the test was easier for the testees than the discrimination part. The test group included Finnish secondary school pupils, (third, fifth and seventh formers), and first-year university students of English. Tommola's discrimination test consisted of minimal pair contrasts and contrasts between two phonetic features, one typically English, the other a typical Finnish substitution feature. The test also comprised a production test, where unconnected sentences were repeated after a model.

Moisio and Valento's study (1976) concentrated on discovering the difficult English consonants for native Finnish speakers to distinguish and produce. One aim of their study was to find out if contrastive analysis could predict possible difficulties. The results showed that the consonants /f, v, θ, ð/ were extremely difficult to distinguish from each other. Moreover, the sibilants and fricatives which are not part of the Finnish sound system caused the most problems in production. Among more recent studies concerning Finnish speaker’s English pronunciation skills, one could mention Lintunen’s (2004) doctoral thesis. He investigated the English phonemic transcription and pronunciation errors of Finnish university students and came to the conclusion that transcription may have some predictive value of the level of the pronunciation skills.

Behavioural studies concerning the production and/or discrimination skills of foreign language phonemes can be found (Rosenman, 1987; Tsubota et al., 2004), but only a very few of these are concerned with pronunciation in the light of musicality (Gilleece, 2004).

3.3. Mismatch negativity (MMN)

The methods employed in judging the level of auditory cortex functioning should, in the most optimal case, be free from attentional influences. Therefore, auditory ERP recordings were used in this study as an objective method in order to evaluate the children’s neural music and speech sound representations. In ERP recordings, electric potentials are measured on the scalp surface, and they are used to detect the activity of the brain. The method is non-invasive, painless and gives very accurate temporal information of the auditory cortex functioning.

Since we receive acoustic information that originates from several simultaneous sound sources, our central auditory system has to be able to segregate this mixture of concurrent sound streams from one another and attribute them to their original sources (Näätänen et al., 1978; Näätänen et al., 2001). The MMN is an ERP component which can be used as an indicator of preattentive auditory processing accuracy, i.e., the ability to track changes in a continuous flow of auditory stimuli, such as the pitch, timbre and location of the origin of the sounds. The MMN is evoked by an infrequently presented deviant sound differing from the frequently occurring stimuli in one or several physical or abstract parameters (Figure 2). Its presence implies that the invariant parameters of the standard sound have been neurally encoded (Näätänen, 2001; Winkler & Cowan, 2005). The MMN can be recorded even when the subject is performing a task unrelated to the stimulation under interest, such as reading a book or playing a computer game. Thus it offers a direct measure for the similarity of neural sound representations without being contaminated by differences, for instance, in the attentional or motivational involvement of the subject (see e.g., Kujala et al., 2006, Näätänen 2007).

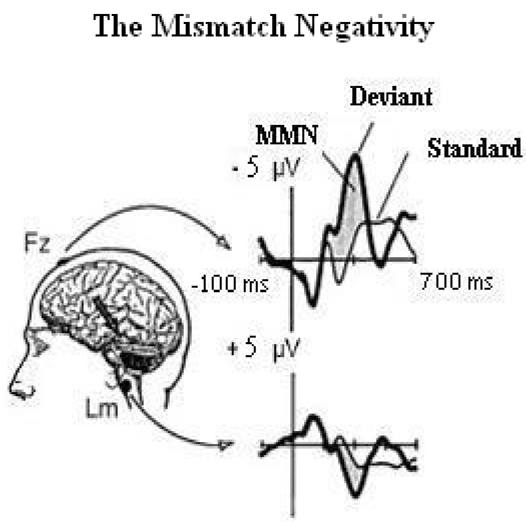


Figure 2. The Mismatch Negativity (MMN, indicated by the shaded area) is usually maximal at fronto-central areas (FZ). The MMN reverses polarity at the mastoid electrodes (LM). Modified from Kujala & Näätänen (2001).

MMN is related to auditory sensory memory functioning (for a review, see Schröger, 1998). The memory traces underlying MMN last about 10 seconds (Sams et al., 1993), may contain multiple items (Winkler et al., 1992) and represent the temporal structure of a sound pattern (Winkler & Schröger, 1995). It is particularly important in the present context that long-term learning processes and permanent sound recognition and discrimination are also reflected by MMN (Näätänen et al., 2001). Second language learning changes the MMN response in both children (Cheour et al., 2002; Peltola et al., 2005) and in adults (Winkler et al., 1999). In addition to this, musical expertise is reflected in MMN (Tervaniemi et al. 2001; Koelsch et al., 1999). Further, MMN can provide evidence for brain lateralization: an MMN response to linguistic changes is elicited more strongly in the left temporal lobe (Shtyrov et al., 2000; Pulvermüller et al., 2001) and non-linguistic changes seem to provoke more action in the right hemisphere (Giard et al., 1995). Moreover, the better the preattentive auditory discrimination skills are, the more MMN is elicited (Näätänen et al., 1993).

4. Aims of this study

The relationship between musical aptitude and linguistic abilities, especially in terms of second language pronunciation skills in children and adult subjects, was examined.

The laterality effects among children and adult groups, musical/non-musical and English philology students were investigated by a Dichotic listening test. Special attention was paid to Forced-Right (FR) and Forced-Left (FL) conditions in order to determine whether these two are differentially affected by musico-linguistic abilities and age.

We also examined 10-12-year-old elementary school children’s ability to preattentively process musical features, namely pitch in music stimuli and duration in music and speech stimuli, using the MMN paradigm. The hypothesis was that the participants with good foreign language pronunciation skills would represent musical sound features more readily in the attentive and preattentive levels of neurocognitive processing compared with those participants with less-advanced pronunciation skills. Sound processing accuracy was examined by means of ERP recordings in MMN paradigm and behavioural measures.

5. Methods

5.1. Participants

The participants of all the experiments of the present thesis were either monolingual Finnish speaking children (age range 10-12) or young adults (age range 20-29). All participants were voluntary. The children were recruited from four demographically similar elementary schools in Turku, Finland. Each child gave informed consent according to the Helsinki Declaration, including a parent's signature. The adult subjects were recruited by displaying advertisements on notice boards around the campus of the University of Turku or sending e-mails via the university's mailing lists.

All subjects had normal hearing abilities as evidenced by clinical audiometer (Inter acoustics model, AC4 serial 0204, Denmark) test results. None of the subjects had any attentional or neurological disorders. To rule out the possibility that the differences in test results might arise from differences in the cognitive capacity of the subjects, the subjects were tested by WISC-III / WAIS.

The Seashore Musical Aptitude Test (described in detail in 5.2.1) was used in all the experiments in order to screen which subject candidates would be motivated and have the necessary patience to continue to the next experimental sessions (i.e. the dichotic listening test, minimal pair discrimination test, etc).

5.2. Experiments and procedure

5.2.1 Seashore test

The Seashore musicality test was chosen for this study since it is a valid and functional musical aptitude test with the longest traditions and is still commonly used. Importantly, it has percentile equivalents of raw scores for each subtest for different age groups of subjects since our subjects consisted of school children and adults. The test measures the accuracy and threshold of auditory discrimination (Seashore et al. 1960; 2003). The test consists of Pitch, Loudness, Rhythm, Time, Timbre and Tonal memory tasks:

1) Pitch subtest: Fifty pairs of tones are presented in sequence; in each pair the participant determines whether the second tone is higher or lower in pitch than the first tone.

2) Loudness subtest: Fifty pairs of tones are presented. The participant has to indicate for each pair whether the second tone is stronger or weaker than the first.

3) Rhythm subtest: The test of the sense of rhythm consists of 30 pairs of rhythmic patterns. The participant indicates whether the two patterns in each pair are the same or different.

4) Time subtest: The test of the sense of time includes 50 pairs of tones of different durations. The individual determines whether the second tone is longer or shorter than the first.

5) Timbre subtest: This test consists of 50 pairs of tones. In each pair the participant judges whether the tones are the same or different in timbre or tone quality.

6) Tonal Memory subtest: This test has 30 pairs of tonal sequences consisting of 10 items, each of three-, four-, and five-tone spans. In each pair, one note is different in the two sequences, and the individual identifies which note it is by number.

The Seashore Measures of Musical Talents test is also described in Paper 3. Noise reduction via digital signal processing techniques was conducted in order to improve the test quality since the original audio files, recorded from the Seashore LP record were corrupted with both impulsive and broadband background noise (see also Paper 3).

5.2.2 Dichotic listening experiment

The Finnish version (modified by Jyrki Tuomainen, 2000) of the original “DLCV-108” dichotic listening test by Hugdahl (Hugdahl & Andersson, 1986) was used in order to determine the laterality effects among the following groups: children, adults, musical subjects, non-musical subjects and English philology students. Special attention was paid to Forced-Right and Forced-Left conditions to determine whether these two are differentially affected by musico-linguistic abilities and age. The experiments were carried out during the school day in a quiet test room or in equivalent conditions in Centre for Cognitive Neuroscience laboratories, University of Turku.

5.2.3 ERP experiments

Two different ERP experiments were run in the Centre for Cognitive Neuroscience EEG laboratories. 40 children participated first in an experiment in which the stimuli investigated were a 150ms C-major triad chord and its two mistuned modifications of equal length played with the violin. In the mistuned stimuli, the major third was either 2% (one third semitone) or 4% (two thirds of a semitone) flat (Study 3).

In the second ERP experiment, the ability to perceive durational differences with speech and music stimuli was examined with the same subjects. The standard speech stimulus consisted of a 250 ms long monaural recording of the Finnish vowel /ö/ and the shorter deviant speech stimulus /ö/ with a 150ms duration. The music sound was a violin tone C4, fundamental frequency 261.3 Hz. The standard and deviant durations of the violin tones were equivalent to those of the speech sounds (Study 4).

5.2.4 Pronunciation test and minimal pair discrimination tasks

In the present thesis, there were behavioural studies of three types: A pronunciation test, in which English phonemes that are typically difficult for Finnish speakers were read onto a minidisc player after a native speaker model (Studies 1, 3, 4). A discrimination task of phonemic minimal pairs was also conducted (Studies 1 and 3), and finally an analogous discrimination task of musical minimal pairs (Study 3), namely chords that differ slightly in pitch. The experiments were carried out during the school day in a quiet test room or in equivalent conditions in the Centre for Cognitive Neuroscience laboratories.

The children completed the behavioural experiments twice, before and after a two-month pronunciation self-training period at home (Study 3). The adults performed the behavioural experiments once (Study 1).

5.3 Statistical analyses

Study 1:

With all the tests (musical aptitude, pronunciation and phonemic tasks), the statistical significances in the test performances were determined by analysis of variance (one-way ANOVA). Significant effects were further analyzed with Tukey’s HSD post-hoc tests for selected contrasts. Furthermore, a multivariate analysis of variance (MANOVA) with ‘years of music training’ as a covariant was conducted in order to clarify how extracurricular music practice might affect the results of the Seashore musical aptitude test, pronunciation and phonemic discrimination tasks. The correlations between general musical aptitude, pronunciation skills and the phonemic listening discrimination tests were calculated by using the Pearson correlation co-efficient, which was also used when blind raters evaluated the pronunciation skills. Additionally, partial correlations were calculated between the general musical aptitude and pronunciation skills, controlling for ‘years of musical training’, and the test scores for WAIS-R and phonemic discrimination skills.

Study 2:

The effects of age on lateralization in both age groups were studied with a repeated measures ANOVA [Age (adult, child) * Ear (left, right) * Condition (NF, FR, FL)]. The statistical significances of the group differences in DL performance were determined by ANOVA for the NF, FR, and FL conditions. In order to test the presence of significant ear advantages separately in different age groups, Age (adult, child) and Ear (left, right) were used as factors.

The effects of musical aptitude on ear advantages in all the subgroups were tested with one-way ANOVA. Significant effects were further analyzed with Tukey's HSD post-hoc tests for selected contrasts. ANOVA was also used in order to determine the group differences in musical aptitude skills. Moreover, a laterality index score [(RE-LE) / (RE+LE) * 100] was calculated, and the statistical significances of the group differences were investigated with ANOVA. If a group main effect was found, the laterality index score was correlated with the musical aptitude score.

Study 3:

ERP:

The stimuli were presented at an inter-stimulus interval (ISI) of 550-650 ms binaurally at 50dB above hearing threshold. In both conditions, there were 1000 trials of which 85% were standards and 15% deviants. At least two standards preceded each deviant tone.

The continuous EEG data were filtered with a band-pass of 0.5 to 20 Hz and divided into epochs of 700 ms duration including a 100 ms pre-stimulus baseline. The MMN was quantified from individual difference waves using a 50 ms time window centred on the peak of the MMN in the individual difference waves at the Fz electrode.

First, the significance of the MMN was determined by comparing the Fz amplitude values to zero by using the one-sample t-test (two-tailed). Thereafter, possible group differences in the MMN amplitude and topography were tested by 3-way ANOVA. Data from 9 electrodes (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4) were entered into repeated measures ANOVA with Group (advanced pronunciation/less-advanced pronunciation) as a between-participants factor, and Laterality (left, middle, right electrodes) and Frontality (anterior, central, posterior electrodes) as within-participant factors separately in both test paradigms; in other words, the C-major triad ($\mathcal{C}$) contrasted with the C-major 2% triad ($\mathcal{C}^{2\%}$), and the C-major triad contrasted with the C-major 4% triad ($\mathcal{C}^{4\%}$).

Behavioural tests:

In all the behavioural tests (musical aptitude, production, phonemic and chord discrimination tests), the statistical significances in the test performances were determined by ANOVA. The participants' musical aptitude and production skills were examined in one-way ANOVA. Repeated-measures ANOVA was used when investigating the participants' success in the phonemic and chord discrimination tests, before and after the training. When evaluating the production test, the correlations were calculated using the Pearson correlation co-efficient.

Study 4:

ERP:

The stimuli were presented at a constant stimulus-onset asynchrony (SOA) of 750 ms binaurally at 50dB above hearing threshold. In both conditions, there were 1000 trials of which 85% were standards and 15% deviants. At least two standards preceded each deviant tone.

The continuous EEG was filtered with a band-pass of 0.5 to 20 Hz and divided into epochs of 700 ms duration including a 100 ms pre-stimulus baseline. The MMN was quantified from grand-average difference waves (obtained by subtracting ERPs to standards from those to deviants) using a 50 ms time window centred on the peak of the MMN in the group difference waves at the Fz electrode and the mastoid electrodes. In both conditions in both groups of subjects, the peaks were determined within the time window of 200-400 ms. The significance of the MMN was determined by comparing the amplitude values to zero by the one-sample t-test (two-tailed).

Possible group differences in MMN amplitude and topography were tested by ANOVA. For this analysis, MMN amplitudes were also quantified at the latency of the most negative peak of the Fz electrode in the group difference waves using 50 ms time windows.

In order to assess the differences between the two groups in scalp distributions in the responses for the different stimuli**,** data from 9 electrodes (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4) were entered into repeated measures ANOVA with Group (advanced pronunciation + more musical aptitude / less advanced pronunciation + less musical aptitude) as a between-subjects factor, and Sound (C4, vowel) and Laterality (left, middle, right electrodes) / Frontality (anterior-central-posterior) as within-subject factors.

Behavioural tests:

In the behavioural tests, the statistical significances in the test performances were determined by one-way ANOVA. The correlations between the general musical aptitude score, the Seashore subtest scores, and the pronunciation skills were calculated using the Pearson correlation co-efficient.

In this thesis, all statistics were computed with the SPSS statistical software.

6. Results

6.1 Adults with musical aptitude have superior pronunciation skills (Study 1)

Milovanov et al. (resubmitted) reports a study investigating the relationship between individual differences in foreign language pronunciation and musical aptitude with three adult test groups of Finnish learners of English: non-musical university students, choir members and English philology students. The subjects were tested on the production of English phonemes and on a discrimination task of phonemic minimal pairs. Their musical aptitude was determined by the Seashore musicality test (Figure 3).

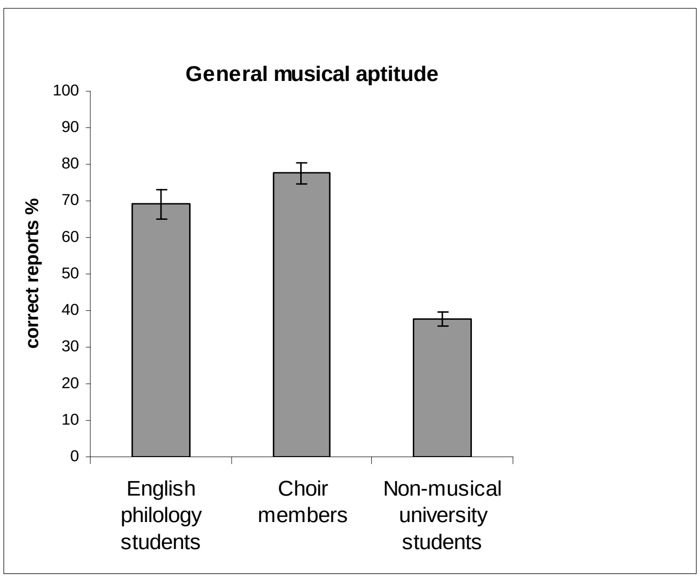


Figure 3. Percentage of correct reports (mean and SEM) from the Seashore musical aptitude test.

Performance on the English phoneme discrimination test was not found to predict English phonemic production ability. Moreover, the phonemic discrimination ability (Figure 4) did not differ between the three test groups ($p>0.05$).

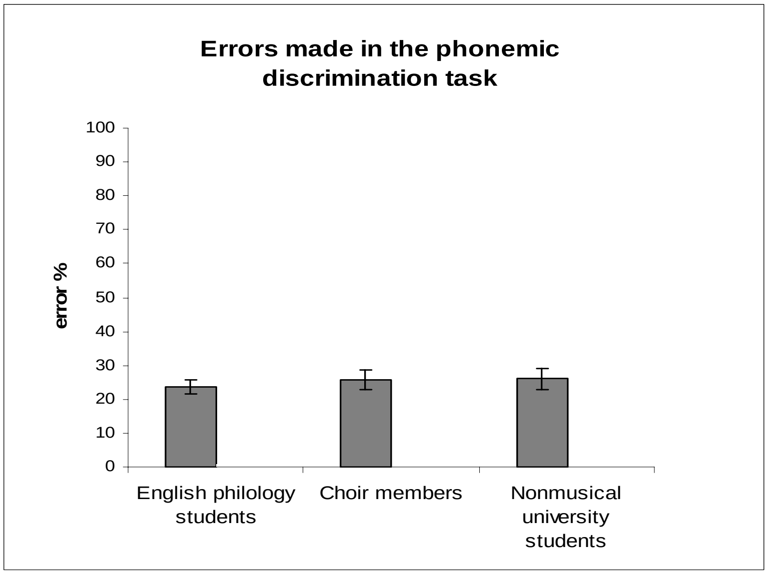


Figure 4. Percentage of errors (mean and SEM) from the phonemic minimal pair discrimination test.

Performance on the English pronunciation test was better for subjects with musical aptitude than with less musical aptitude (Figure 5).

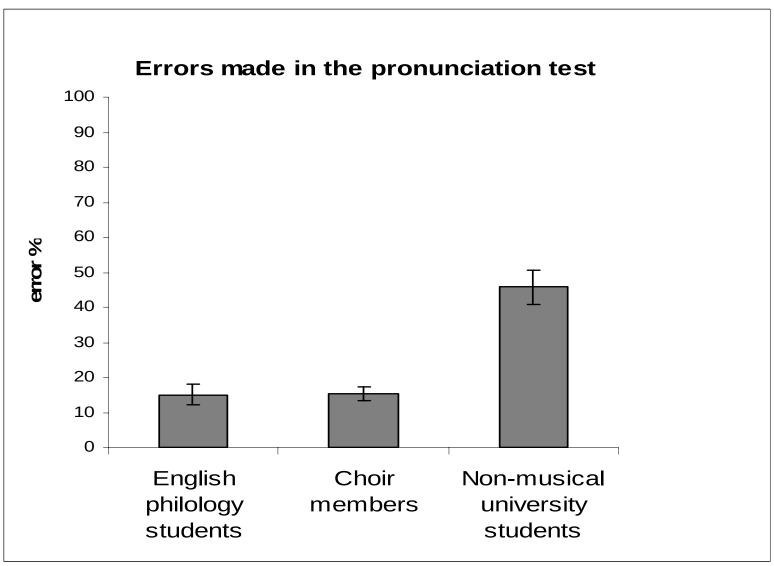


Figure 5. Percentage of errors (mean and SEM) in the pronunciation test.

These results imply that musical aptitude is interconnected with phonological ability in second language learning.

6.2 *Altered hemispheric functioning with adults practicing music regularly (Study 2)*

The aims of Milovanov et al. (2007) were to determine the effects of age and musical ability on phonemic processing in a forced-attention dichotic listening paradigm. Subjects differing in musical ability, as tested with the Seashore musical aptitude subtests of pitch discrimination, duration, timbre, and tonal memory accuracy, listened to consonant-vowel (CV) syllables presented dichotically under three different attention instructions: Non-Forced, Forced-Right and Forced-Left conditions. No significant group difference was found between the test performances of the choir members and English philology students, the English philology students and musically advanced children, and the choir members and musically advanced children in the Seashore test. However, the group differences between any other groups were significant (Figure 6).

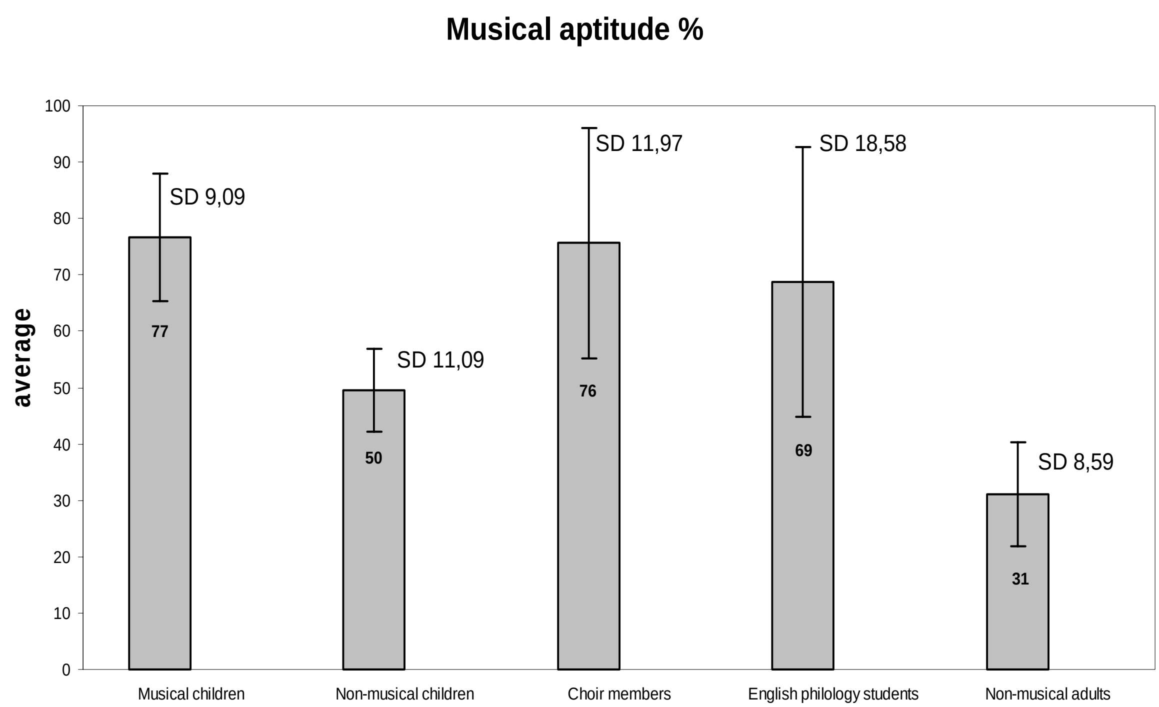
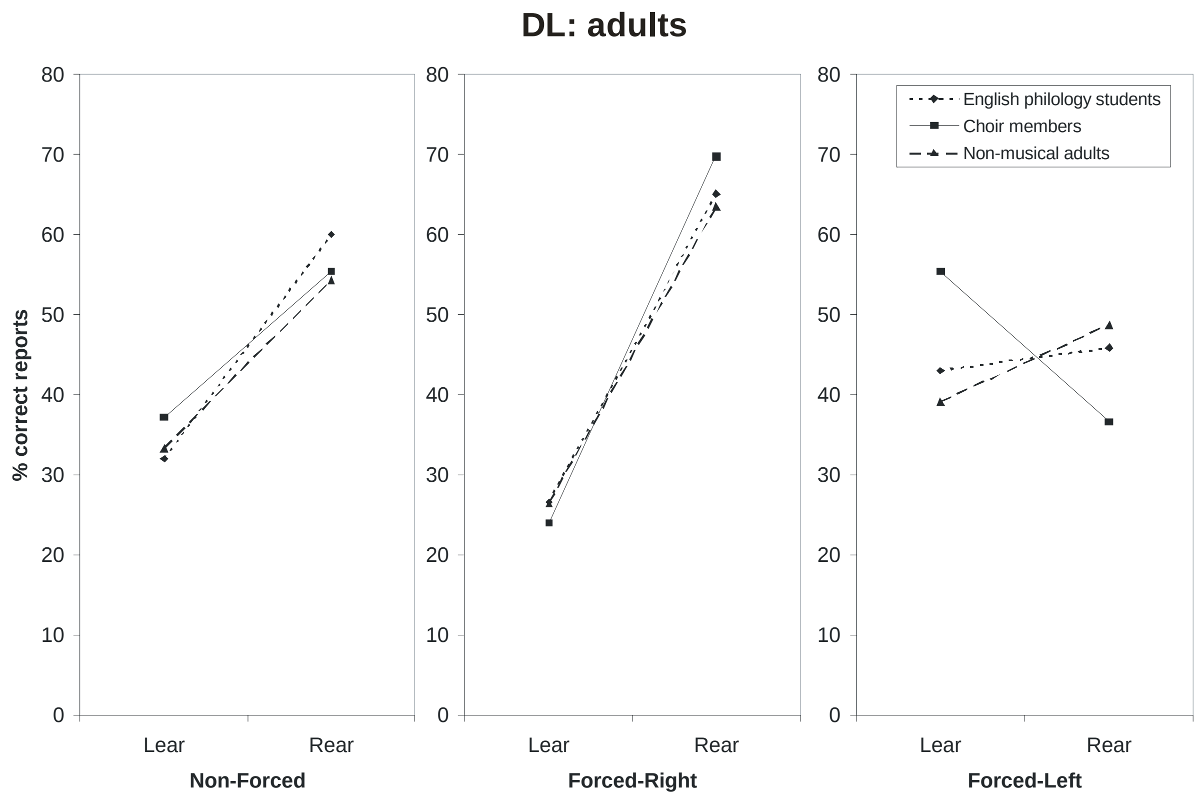


Figure 6. Percent correct reports from the four Seashore musical aptitude subtests: pitch discrimination, duration, timbre and tonal memory accuracy.

The results showed that musical ability and age interacted with the ability to use attention to modulate a bottom-up laterality effect. In other words, only those adults who performed well in Seashore's test showed more accurate left ear monitoring skills when listening to Finnish phonemes (Figure 7). No such effect was seen with children, with or without musical aptitude.


DL: adults
% correct reports
80
70
60
50
40
30
20
10
0
Lear
Rear
Non-Forced
Forced-Right
Forced-Left
English philology students
Choir members
Non-musical adults

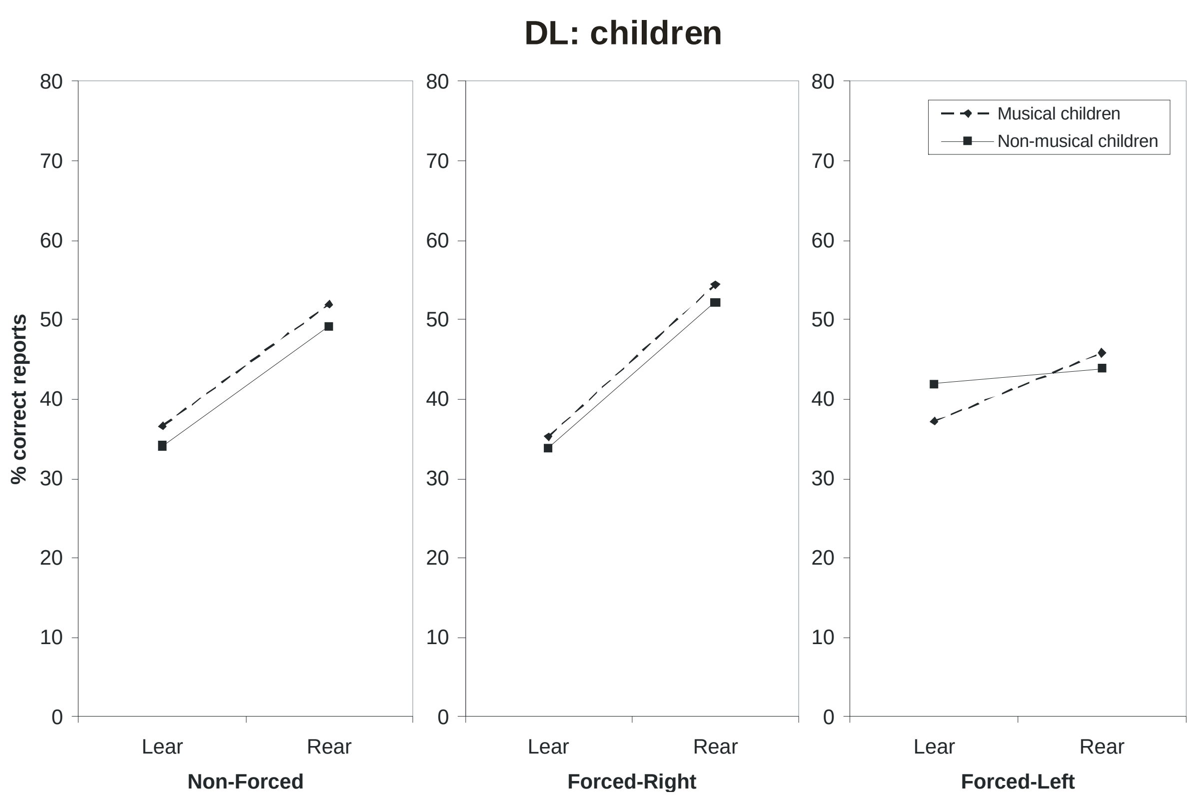

DL: children
% correct reports
80
70
60
50
40
30
20
10
0
Lear
Rear
Non-Forced
Forced-Right
Forced-Left
Musical children
Non-musical children

Figure 7. Percentage of correct reports for the left (Lear) and right (Rear) ear stimuli during all three conditions (Non-Forced, Forced-Right, Forced-Left) split for the results obtained from the adult subgroups (upper row) and children subgroups (lower row).

Based on the result described above, it can be inferred that the musical subjects use the right hemisphere more in language processing when compared to the non-musical subjects. Musical subjects may also pay more attention to the musical components of language than the non-musical subjects.

6.3 *Musical and phonemic discrimination skills interact at both the behavioural and neural level (Study 3)*

Milovanov et al. (2008) examined the relationship between musical aptitude and second language pronunciation skills. 20 children with advanced English pronunciation skills had better musical skills as measured by the Seashore musicality test than 20 children with less accurate English pronunciation skills. The individual Seashore subtests indicated that the participants with advanced pronunciation skills were superior to the participants with less-advanced pronunciation skills in pitch discrimination ability, timbre**,** sense of rhythm, and sense of tonality. The results in time or loudness subtests did not differ significantly between groups (Figure 8).

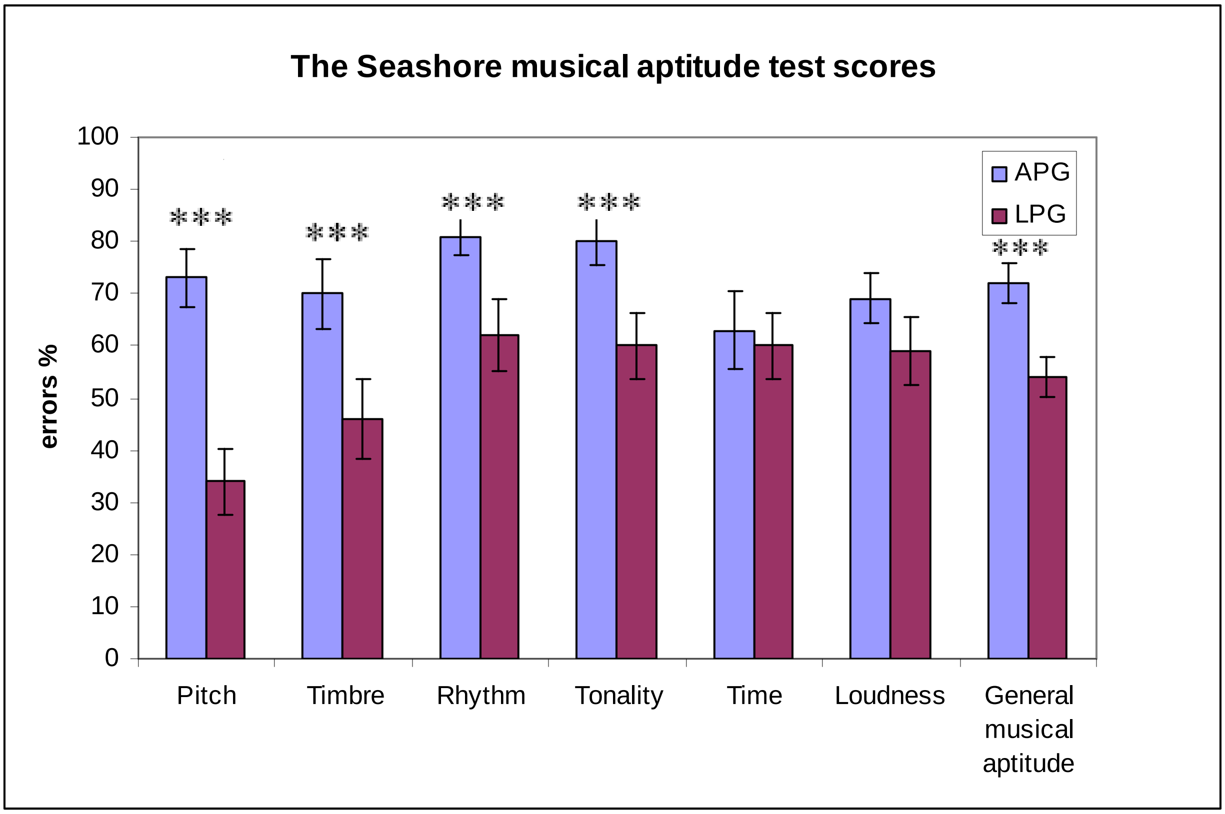


Figure 8.Percentage of correct reports (mean and SEM) from the Seashore musical aptitude test. Significant mean differences between APG (= advanced pronunciation group) and LPG (= less-advanced pronunciation group) are shown by *** with a significance level of $p < 0.001$.

The children's ability to produce correct English phonemes with no direct equivalents in Finnish was determined. To ensure that all the children had an adequate amount of pretraining in the pronunciation of English, they received an 8-week course of pronunciation training in English including phonemic discrimination exercises.

Moreover, two behavioural discrimination tests were conducted, both before and after the pronunciation training period. First, the children were required to distinguish the phonemic dissimilarities between English and Finnish through triplets based on minimal pair contrasts of the phonemes, e.g. a) jeep - jeep- cheap, b) they - day - they. After that, a C-major triad, assigned here the symbol $\mathfrak{C}$, and its two mistuned modifications $\mathfrak{C}^{2\%}$ and $\mathfrak{C}^{4\%}$ were investigated following the principles of the phonemic discrimination test.

As seen in Figure 9, the results of the phonemic and triad tests of the advanced pronunciation group did not differ significantly before or after the training. Nevertheless, the advanced pronunciation group outperformed the participants with less-advanced pronunciation skills in terms of a higher amount of correct answers and a smaller amount of mistakes in both the music and phonemic discrimination tests. For the less-advanced pronunciation group, triad contrasts were more difficult than the phonemic contrasts both before and after the training. Both test groups marginally improved their phonemic discrimination skills after the training. Interestingly, the training period did not only develop the participants' linguistic skills but also strengthened the discrimination skills of musical sounds, especially in the participants with advanced pronunciation skills.

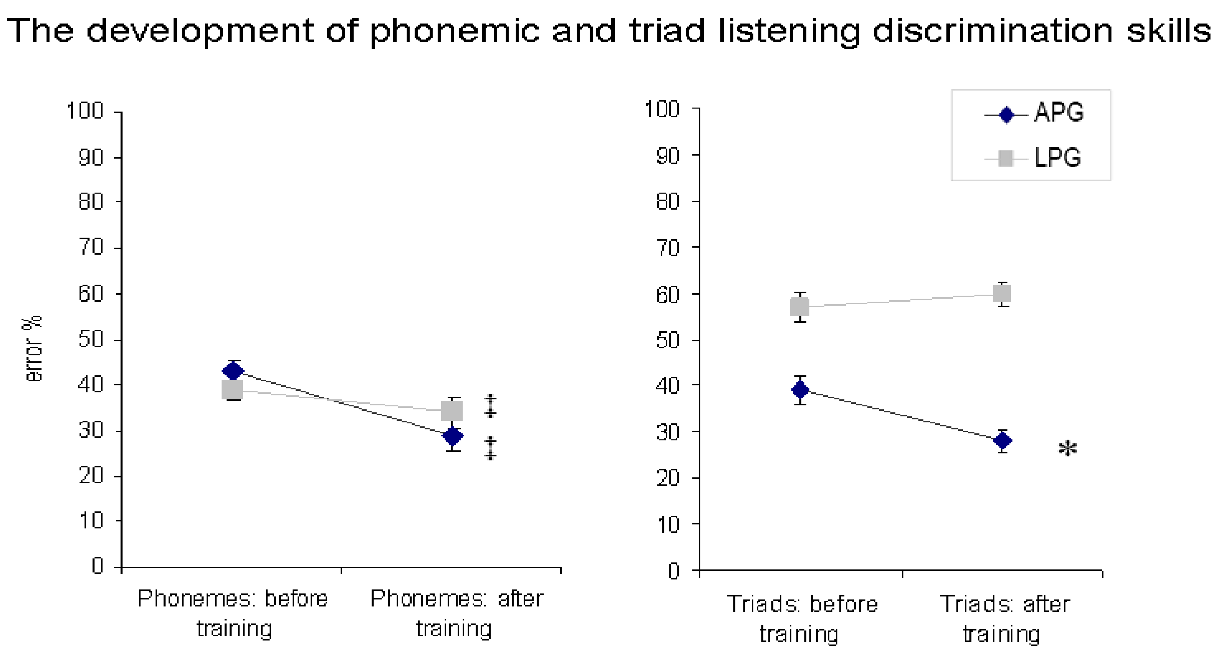


Figure 9. Percentage of errors (mean and SEM) from the phonemic and triad discrimination tests before and after the pronunciation training. Significant mean differences between APG = (advanced pronunciation group) and LPG (less-advanced pronunciation group). A significant change between before and after training is marked by * ($p<0.05$). Additionally ‡denotes $p<0.1$.

We also investigated whether children with a more advanced performance in foreign language production represent musical sound features more readily in the preattentive level of neural processing compared with children with less-advanced production skills. Sound processing accuracy was examined by means of ERP recordings. The accuracy of the auditory cortex in representing musical sounds [a C-major triad, assigned here the symbol $\mathbb{C}$, and its two mistuned modifications $\mathbb{C}^{2\%}$ and $\mathbb{C}^{4\%}$] was examined by means of ERP recordings in the MMN paradigm. In the mistuned stimuli, the major third was either 2% (one third semitone) or 4% (two thirds of a semitone) flat.

The ERP data accompany the results of the behavioural tests: The advanced pronunciation group showed larger fronto-central MMN with the music stimuli than the less-advanced pronunciation group. The MMN lateralization pattern did not differ between the test conditions nor the test groups. (Figures 10 and 11).

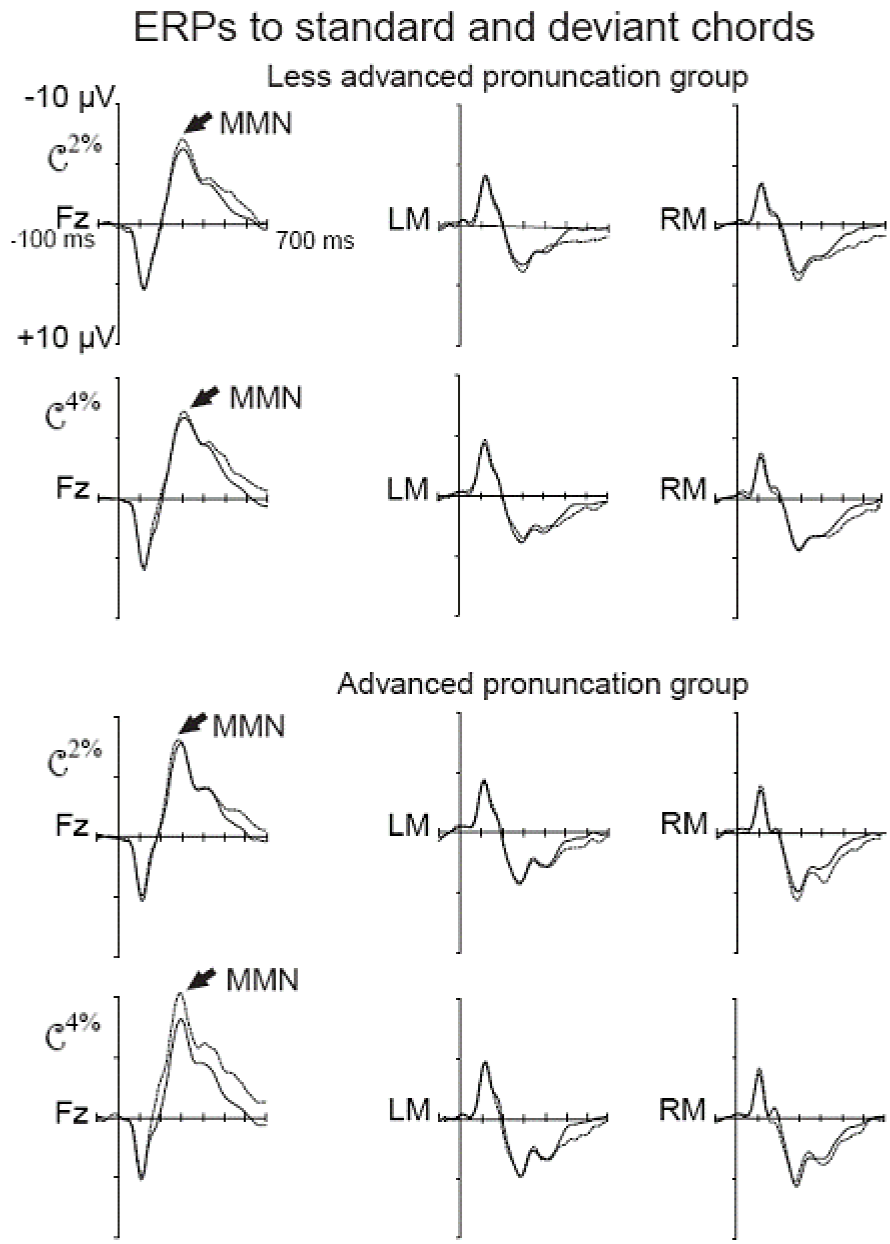


Figure 10. The standard (solid line) and deviant (dashed line) ERPs for both $\mathbb{C}^{2\%}$ and $\mathbb{C}^{4\%}$ conditions from the Fz, LM (left mastoid) and RM (right mastoid) electrodes.

$\mathbb{C}^{4\%}$ condition subtraction waveforms $\mathbb{C}^{2\%}$ condition subtraction waveforms

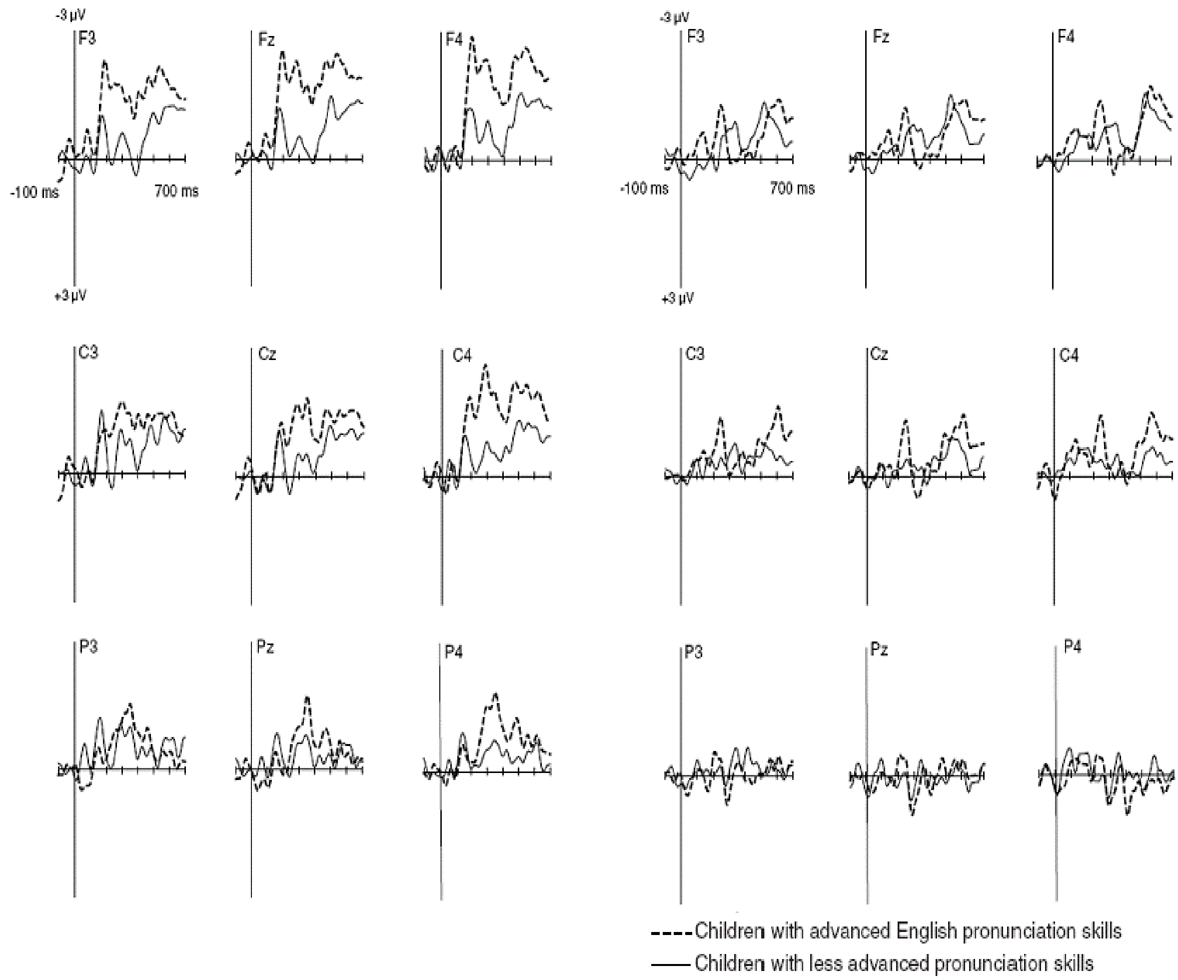


Figure 11. Difference waveforms in $\mathbb{C}^{4\%}$condition (left) and $\mathbb{C}^{2\%}$ condition (right), computed from subtracting standard from deviant.

Taken together, the results imply that musical and phonetic skills could partly be based on shared neural mechanisms.

6.4 The role of musical elements in preattentive duration processing (Study 4)

Milovanov et al. (2009) aimed at comparing the duration discrimination skills between both music and vowel condition. The subjects were the same as described in Study 3. ERP data show that, irrespective of general musical aptitude, duration changes from 250 to 150 ms are more prominently and accurately processed in music than in speech sounds (Figure 12). In addition, the subjects with advanced pronunciation skills and greater musical aptitude were able to preattentively discriminate the duration difference in both conditions more effectively than the less-advanced pronunciation group with less musical aptitude. Only the advanced pronunciation group showed an MMN lateralization effect. Larger MMN amplitudes were found in the right hemisphere (Figure 12), as also in the majority of previous linguistic (electric) MMN-studies, despite the dominance of the left-hemisphere contribution in higher-level linguistic functions.

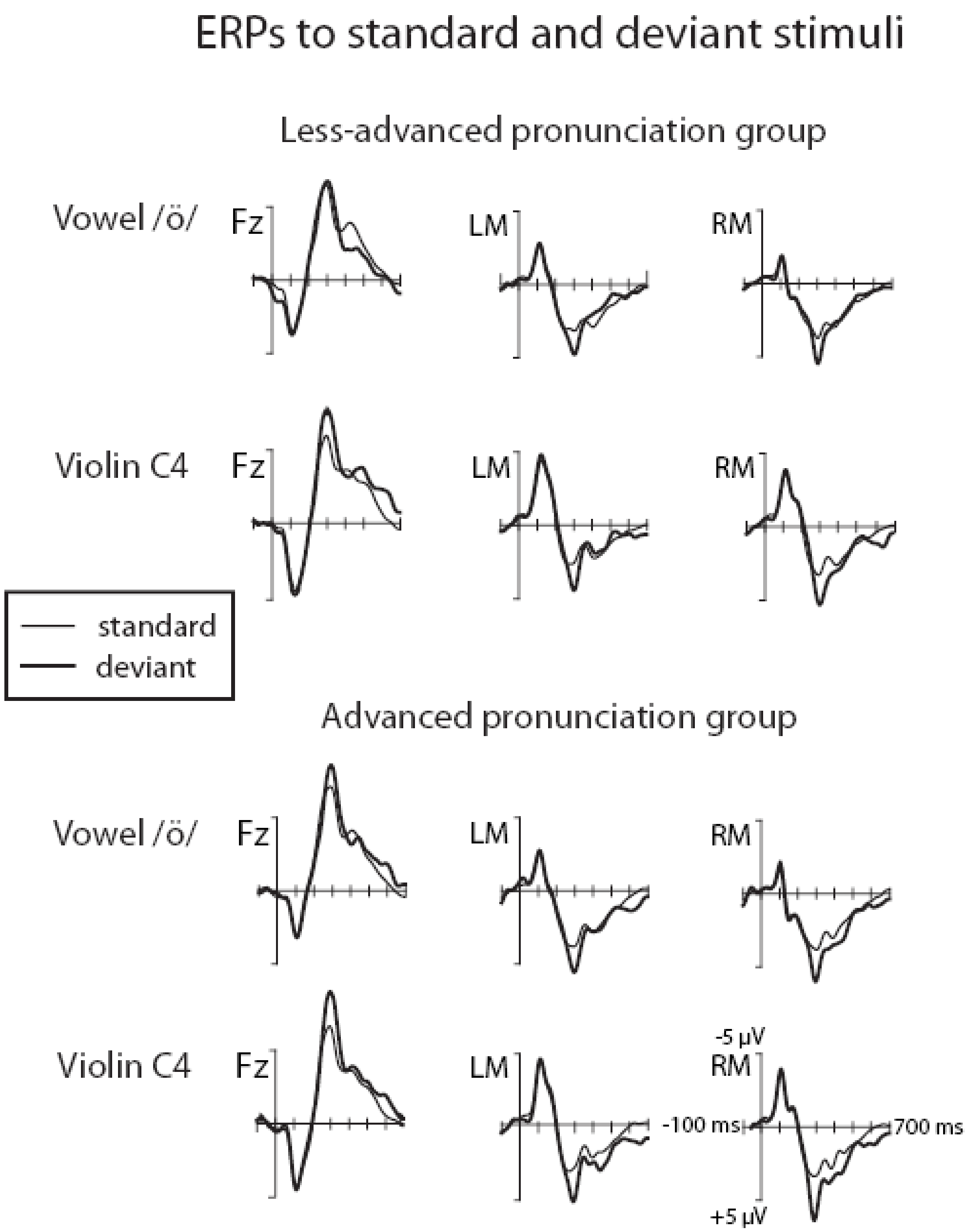


Figure 12. The standard (thin line, 250 ms) and deviant (bold line, 150 ms) ERPs in the vowel condition and violin condition at the Fz, LM (left mastoid) and RM (right mastoid) electrodes in the less-advanced pronunciation group (upper panel) and advanced pronunciation group (bottom panel).

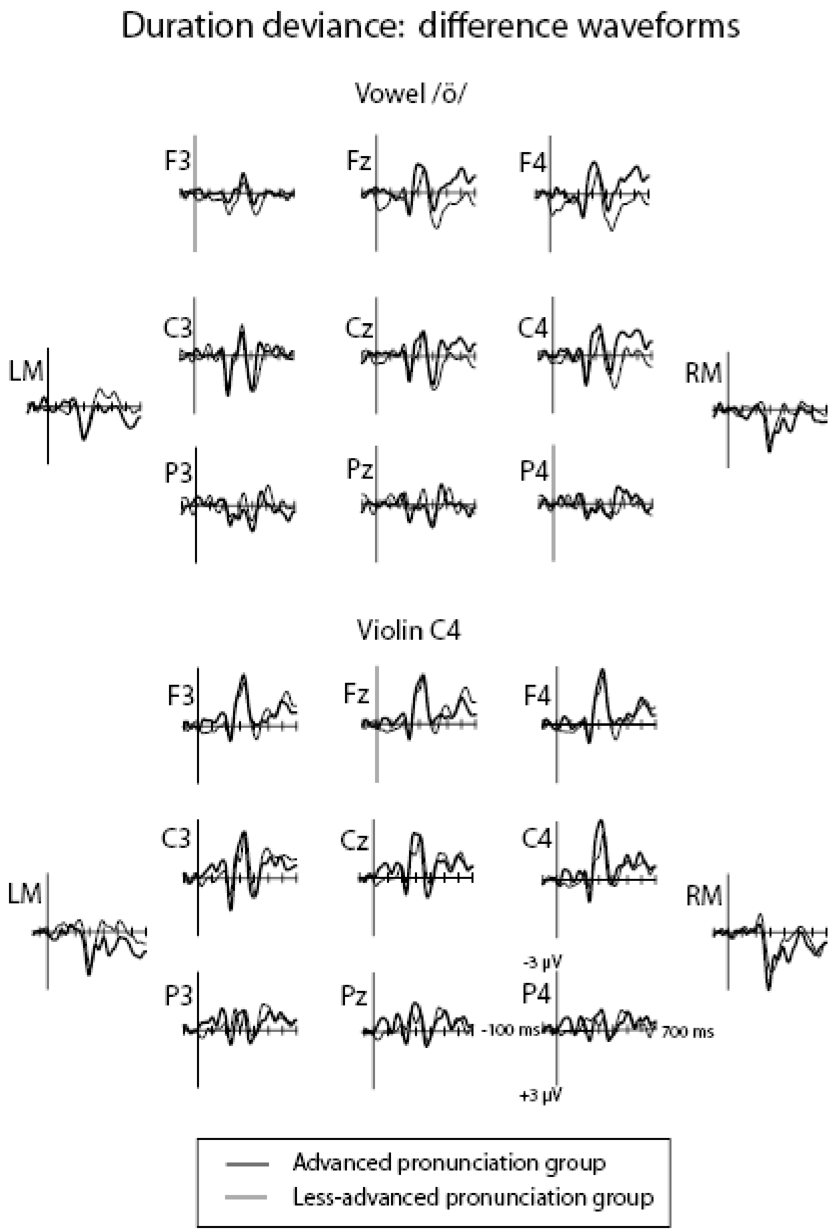


Figure 13. Difference waveforms in Vowel condition /ö/ (above) and Violin condition /C4/ (below), computed by subtracting standard from deviant.

On the basis of the results obtained above, it could be suggested that the musical aptitude and phonetic skills are interconnected, and the musical features of the stimuli could have a preponderant role in preattentive duration processing.

7. Discussion

This thesis aims at determining whether musical aptitude could be a crucial factor in learning foreign language pronunciation and discrimination skills, and at discussing the relationship between music and language in general. To this end, the facilitating role of musical aptitude on foreign language pronunciation acquisition and phonemic and listening discrimination skills was determined in children and adult subjects without any neurological disorders or learning disabilities. Their musical aptitude was examined by the Seashore measures of musical aptitude (1967, 2003).

The English pronunciation skills were evaluated by the subjects' ability to pronounce words after the model of a native speaker. The children studied English pronunciation for 8 weeks and had phonemic discrimination exercises before the evaluation of the pronunciation skills. The adult subjects did not take the study period at home because of their minimum 7 years of English studies at school. The participants' ability to track differences in a minimal pair listening discrimination task was evaluated. Both musical (triads) and phonemic minimal pair tests were run. For control purposes, the cognitive capacity of the subjects was determined by WISC III / WAIS. No significant differences in linguistic capacity was found between any of the test groups. The performance IQ of the children's advanced pronunciation group was better than the group with less-advanced pronunciation skills. Nevertheless, this was not the case with adult subjects.

Dichotic listening scores were obtained with 69 subjects in order to study the laterality effect of the mother tongue and musical aptitude. Two different ERP studies were run with 40 children in order to see the cortical processing of musical and speech stimuli. The first study concentrated on musical pitch, the second ERP study was about vowel and musical durational differences. Both ERP results indicated that musical and phonetic skills are interconnected, and subjects with musical aptitude and better phonetic abilities reacted more strongly to musical speech stimuli preattentively than their controls, subjects with less musical ability and weaker phonetic skills. Moreover, when the preattentive skill to discriminate durations was investigated, only the subjects with more musical aptitude had a lateralization effect on the right hemisphere. The advanced pronunciation group evoked a stronger MMN than the less-advanced pronunciation group to both durational changes. The dichotic listening test also provided evidence about the connections between musical aptitude and linguistic abilities; more effective right hemispheric functioning was elicited with musical subjects when mother tongue CV-pairs were listened to.

Musical training may affect the brain's linguistic processing skills. The foreign language phonemic pronunciation results were in accordance with the general musical aptitude score, the more musical aptitude the subject had, the better the pronunciation test results were.

The role of age

The apparent relationship between music and language seems to be present from the very early stages of life. Music and language seem to grow from a common source ever since birth. Small infants can mime the musical features of their mother tongue long before they are able to produce phonemes. The stress and pitch patterns are there first and more precise phonemic features join the musical features of the language a little later. There has, in fact, been a good deal of controversy around whether the age at which a person is first exposed to a second language, in the classroom or naturalistically, affects the acquisition of that language. Views such as 'younger learners are better' and 'the second language should be introduced prior to puberty' are very common. There are studies which show that the younger the subjects start playing an instrument, the greater the effect on the brain structure or function (Elbert et al., 1995; Schlaug et al., 1995, Pantev et al., 1998). Nevertheless, in the present thesis, the participants' age did not have a crucial role in the accuracy of the pronunciation skills, instead, musical aptitude was found to be the key for better foreign language pronunciation skills.

Shared neural mechanisms between linguistic and musical functions?

The role of possibly shared neural mechanisms between linguistic and musical functions is still unclear even though there is evidence that musical training improves sensory encoding of dynamically changing sounds, which helps with linguistic coding. It is not possible to identify precisely (yet or maybe ever) which brain areas are associated with language or music functioning. Neuropsychological studies mostly imply that music and language are more like independent cognitive functions (Marin & Perry, 1999; Peretz, 2006). Consequently, it has been suggested that the representations for speech and musical sounds are independently encoded in the auditory cortex (Jaramillo et al., 2001; Tervaniemi et al., 2006). However, the increasing body of evidence coming from the area of neuroimaging studies challenges this view by presenting results showing overlap between music and language (Maess et al., 2001). fMRI and PET studies provide further evidence for overlap in brain areas when linguistic and musical structure processing was studied (Tillmann et al., 2003; Brown et al., 2006). Nevertheless, even if music and language processing were spatially detached, why could not the different modes of speech and music domains act in synchrony, supporting one another? The ERP studies presented in this thesis hint that musical and linguistic skills could partly be based on shared neural mechanisms.

Neuroimaging studies present evidence that certain brain areas differ between musicians and non-musicians. One could only speculate if this was the case with the adult subjects presented in this thesis since the dichotic listening test suggests that regular music practice may have a modulatory effect on the brain’s linguistic organization. Superior left ear monitoring skills were found among the adults who practised music regularly. Other musically-talented subjects did not have the ability to control left ear functioning in this manner. This may indicate altered hemispheric functioning with those who have regularly practised music for years.

Conclusions

As Patel (2008) puts it, exploring the network of relations between music and language, the similarities and the differences between the two domains, can improve our understanding of how the mind assembles complex communicative abilities from elementary cognitive processes. In other words, comparing music and language provides a powerful tool for studying the mechanisms that human mind uses to make sense out of sound. Music is one of the oldest, and most basic, socio-cognitive domains of the human species (Koelsch, 2005). Primate vocalizations are determined by music-like features, such as pitch, timbre and rhythm. Fine-grained temporal processing is fundamental to both speech and language (Alcock et al., 2000). Tallal et al. (1991) have proposed that the underlying deficit which leads to language disturbance is control and processing of timing skills. Overy (2003) is of the view that musical training develops temporal processing abilities, which are also relevant to phonological segmentation skills. Hyde & Peretz (2004) showed that amusic subjects were be able to detect durational changes just as well as their controls but possessed degraded pitch perception skills. They suggest that amusia is not specific to only music, but rather is related to a more general, psychoacoustic difficulty in fine pitch resolution. One could possibly consider congenital amusia as a mirror image of some developmental disorders in language since music, as well as language, is organized temporally.

As cognitive and neural systems, it seems that music and language are closely related (Patel, 2008). In the present studies, a significant relationship was found between musical aptitude and second language learning skills, independent of verbal intelligence. It was discovered that advanced musical aptitude enhances learning of foreign language pronunciation. Based on the present results, it is proposed that language skills, both in production and discrimination, are interconnected with perceptual musical skills. According to the present results, the general musical aptitude score and the other four independent subtests of the Seashore musical aptitude test were superior in children with advanced second language pronunciation skills when compared with children with less advance pronunciation skills. It is proposed that the musical subjects are able to more efficiently process the musical features in both speech and language, both attentively and preattentively. Perhaps the participants with less-advanced pronunciation skills overlooked the musical components of language, while those participants with advanced pronunciation skills had found the key to successful foreign language learning by also paying attention to the musical components of speech.

The subjects with advanced pronunciation skills and greater musical aptitude were able to preattentively process the duration difference when presented in the vowel and violin sounds more effectively than the less-advanced pronunciation group with less musical aptitude. Moreover, both triad changes evoked significant MMN responses in both participant groups, although without significant amplitude differences between the groups. Still, the participants with advanced pronunciation skills showed larger fronto-central MMN responses with the $\mathbb{C}^{4\%}$ triad condition than the participants with less accurate pronunciation skills. The results imply that musical and linguistic skills could partly be based on shared neural mechanisms.

One could also speculate whether the superior performance in musical and linguistic tasks draws on the same source, namely an improved auditory discrimination ability. To illuminate this issue still further, testing of more basic auditory processing skills, not directly related to speech or to music-sound listening, should be conducted. For future research, it is also suggested that one could study how systematically developing an individual’s musical aptitude (such as pitch, and tonal memory skills) could also reflect positively in foreign language skills, such as pronunciation. To sum up, the results presented in this PhD thesis provide further evidence that musical aptitude and practising music have a beneficial effect on linguistic skills. It is thus proposed that the number of music lessons should not be cut down in the school curriculums as the current trend seems to be, but rather be increased since the beneficial effects of music on human beings go far beyond learning and improving academic skills.

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