



TURNING INTO THE UNKNOWN: EXPLORING INDIVIDUAL DIFFERENCES IN UNFAMILIAR SPEECH PERCEPTION ACROSS GROUPS

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Research has shown that speech perception ability can vary tremendously depending on mechanisms such as musical ability, musical status second, and/or foreign language capacity. In this study, we wanted to assess individual differences in unfamiliar speech perception (auditory phonological pattern recognition) across diverse groups (children with and without musical training, adolescents and adults with varying levels of foreign language proficiency, with different degrees of musical ability and individuals with ADHD). Our sample consists of 724 participants (including N=56 individuals with ADHD) who voluntarily participated in this study. We divided the participants into different groups according to age (N=77 children; N=171 adolescents; N=476 adults), language and music background and tested them for their ability to perceive unfamiliar languages, as well, we assessed their musical background, their foreign language capacity, their educational status, the educational status of the parents and gender. Our study reveals that musical training has an impact on unfamiliar speech perception across ages. In adolescence, the impact of foreign language capacity and musical training seems to be of equal importance, while in adulthood, musical training surpasses foreign language capacity, particularly in comparison to adolescents. Individuals with ADHD showed reduced speech perception performance, suggesting potential challenges in early foreign language perception that warrant further investigation. In addition, SES based on parental education has been identified as a good predictor to outline individual differences in speech perception. However, current socioeconomic status does not significantly correlate with adult language perception; rather, childhood SES remains the primary determinant of these linguistic variations.

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Keywords: foreign language perception; musicality; socio-economic status (SES); children; adolescents; adults; ADHD, musicians;

1. INTRODUCTION

Research on individual differences in learning foreign languages has focused on multiple domains, such as cognitive abilities (e.g., working memory, short-term memory) (Baddeley 2003; Baddeley 2010), personality traits (e.g., extraversion, anxiety) (Dörnyei and Ushioda 2013), social factors (motivation, peer interaction) (Dörnyei and Ryan 2015; Dörnyei and Skehan 2003), and aptitude measures (Wen 2012; Wen et al. 2019; Wen and Skehan 2011). Foreign language learning is shaped by a mix of cognitive abilities (such as musicality), environmental factors (such as socio-economic status or SES), and prior linguistic experience (such as extensive foreign language capacity). Previous studies have shown that both musical training and musical aptitude, as well as extensive experience with foreign languages, can facilitate the learning of additional

languages (Christiner 2020; Christiner and Groß 2025), suggesting perceptual benefits in processing novel linguistic input. These group differences were particularly pronounced when contrasting neurotypical participants with those diagnosed with ADHD, consistent with prior research on auditory processing differences (Groß et al. 2022; Groß et al. 2023). In this study, we examine the role of socioeconomic status (SES), musicality, and extensive foreign language capacity, as well as ADHD-related differences, shape learners' ability to discriminate between unfamiliar languages, drawing on research linking acoustic, cognitive, and experiential factors across music and language learning.

In the early stages of foreign language learning, acoustic signals are particularly important for successful acquisition. At this stage, utterances are often limited in linguistic content (i.e. lexicon and grammar), and therefore resemble melody learning where acoustic contours dominate. (Christiner et al. 2021). Research has shown that musical skills— particularly singing, – are associated with performance in pronunciation tasks involving unfamiliar languages that simulate learning situations for the acquisition of new vocabulary and phrases (Christiner et al. 2022; Franco et al. 2021; Christiner et al. 2018; Christiner et al. 2021; François et al. 2013). Evidence further suggests that singing ability is directly linked to generating intelligible unfamiliar utterances (Christiner et al. 2023), remembering new vocabulary (Ludke, Ferreira and Overy 2014) and pronouncing unfamiliar languages (Christiner 2020; Christiner et al. 2023; Christiner and Renner et al. 2022). In addition, measures of singing ability – such as direct singing performance tasks and self-assessed singing ability – have been associated with the capacity to imitate foreign accents convincingly (Coumel et al. 2023). Research on children further shows that participation in singing activities and vocal play promotes the development of advanced vocal abilities. (Calì 2017; Christiner and Reiterer 2018; Franco et al. 2021; Thiessen and Saffran 2009), Accordingly, individuals who sing frequently during childhood appear to retain a certain degree of vocal plasticity for producing new sounds and unfamiliar languages in adult life (Christiner, Bernhofs and Groß 2022). On the contrary, singing ability and singing performance rarely explain individual differences in unfamiliar foreign language perception tasks (Christiner, Bernhofs and Groß 2022; Coumel et al. 2023). In light of previous research, the benefits of singing appear to depend on at least two factors. First, singing may enhance sensorimotor ability and integration of vocal-motor skills that support various forms of vocalization (Christiner, Bernhofs and Groß 2022; Christiner and Renner et al. 2022). Second, melodic structure may function as a mnemonic device or a memory booster that facilitates memory for linguistic material. (Christiner et al. 2021; Christiner and Renner et al. 2022).

Perceptual research on the overlaps between music and language has shown that musical training improves speech processing and speech perception (Besson, Chobert and Marie 2011; François et al. 2013; Kraus and Chandrasekaran 2010; Thompson, Schellenberg and Husain 2004). In this respect, findings have shown that musical ability influences foreign language proficiency, particularly in the subtle aspects such as the ability to perceive tonal features of languages (Christiner and Renner et al. 2022)

and to segment speech (François et al. 2013). Segmentation of speech patterns is most difficult for learners of foreign languages in the initial stages. They often lack the ability to recognize where utterances begin or end (Patel 2007). As musicians have a sense for rhythmical structures, this may be another fundamental reason why musical capacity is associated with the ability to segment speech (François et al. 2013). Musicians' enhanced pitch perception skills also equip them with an advantage in perceiving non-native lexical tones (Alexander, Wong and Bradlow 2005) and unfamiliar languages more effectively (Christiner 2020).

As outlined, musicians display enhanced auditory processing of both music stimuli (melody/rhythm recognition) (Benner et al. 2017) and speech sounds (Polat and Atas 2014), while neurodevelopmental conditions such as ADHD (Groß et al. 2023) and dyslexia (Christiner and Serrallach et al. 2022; Groß et al. 2022; Serrallach et al. 2016) are associated with challenges in similar tasks (e.g., melody discrimination, word memory).

Research on musicians and language has provided evidence that musical training and musical ability improve language-related functions across multiple domains. From a linguistic perspective, individuals who grow up speaking two or more languages – or who acquire multiple languages during their lives – may share similarities with musicians from a linguistic perspective (Christiner and Groß 2025). In particular, they appear to show advantages in learning new languages (Papagno and Vallar 1995). Researchers distinguish between early and late bilinguals. What they have in common is the generally accepted notion that both early and late bilingualism, as well as multilingualism, can enhance the ability to acquire novel phonological forms (Hell and Mahn 1997; Kaushanskaya and Marian 2009; Papagno and Vallar 1995). It is widely recognized that age plays a crucial role in language acquisition, with earlier exposure to additional languages typically leading to superior outcomes (Johnson and Newport 1989; Lenneberg 1967). Language learners typically apply L1 segmentation strategies, which create perceptual difficulties and transfer errors (Patel 2007). Similarly, they often substitute unfamiliar target sounds with similar native phonemes, or struggle to perceive and produce non-native contrasts (Werker and Tees 2005). Critically, phonetic ability has been argued to be the only linguistic capacity governed by a strict critical period (Moyer 2014), though subsequent research has challenged this view. A relatively low number of individuals can reach native-like foreign language proficiency when they are adults (Selinker 1972). Individuals who learn a second or third language after their first language – such as successive and late bi- and multilinguals, as well as polyglots – have been found to benefit from familiar phonemic inventories and seem to learn further languages faster (Hell and Mahn 1997; Kaushanskaya and Marian 2009; Papagno and Vallar 1995). Therefore, studies also found that the number of foreign languages is related to new word learning and foreign accent imitation (Christiner 2020; Christiner et al. 2021; Hell and Mahn 1997; Papagno and Vallar 1995).

Individual differences in language skills are also associated with differences in social status. As such, socioeconomic status constitutes a key dimension that reflects an individual's access to economic and social resources as well as their social standing,

and it is closely associated with educational and academic attainment (Hauser and Warren 1997; Li, Xu and Xia 2019; Szabó, Polonyi and Abari 2019). The influence of SES on language ability extends across a lifespan, from childhood to adulthood, and continues to affect academic performance. (Hoff 2013). Differences in language abilities between children from high- and low-SES backgrounds reflect disparities in both the quantity and quality of language exposure (Calvo and Bialystok 2014; Cartmill et al. 2013; Huttenlocher et al. 2010; Rowe 2018).

Building on our previous research and findings, we propose that individuals with musical training and extensive foreign language capacity demonstrate superior performance compared to individuals without musical training (Q1) and without extensive foreign language capacity (Q2) in tasks related to language discrimination ability. Given evidence of challenges in auditory processing among individuals with ADHD, we hypothesize differences in language perception performance between individuals with and without ADHD (Q3). Our research design also integrates singing self-estimation criteria and the average weekly singing frequency as variables. We hypothesize that none of these singing-related variables will exhibit a significant association with the perception of unfamiliar speech (Q4). We hypothesize that parental SES influences participants' language abilities but not necessarily their educational attainment. (Q5). Although three age groups (children, adolescents, and adults) were included in the present study, the design was not intended as a longitudinal lifespan investigation. Rather, the age groups were compared cross-sectionally to explore whether the influence of musical training, foreign language capacity, socioeconomic status, and ADHD differs across developmental stages. Accordingly, the findings should be interpreted as cross-sectional comparisons rather than evidence of developmental trajectories.

2. MATERIALS AND METHODS

2.1. Participants

We recruited 724 participants who participated voluntarily in this study. All participants were native speakers of German. A small subgroup reported a bilingual upbringing (see respective group descriptions below). None of the participants reported prior exposure to or proficiency in any of the unfamiliar target languages used in the speech perception task (Tagalog, Mandarin, Farsi, Japanese). We divided the participants into different groups according to age, language, and music background. Participants who did not match any of our descriptors and did not finish the entire testing battery were excluded from the analysis. Participants reported normal hearing and no history of diagnosed hearing impairments. Individuals with known neurological or auditory disorders were excluded from participating. A formal audiometric screening was not conducted. As we have defined several variables, we have compiled a list of abbreviations to facilitate understanding (see table 1).

Table 1. List of abbreviations.

Abbreviation	Meaning
EFL	Extensive Foreign Language Capacity
NoEFL	Without Extensive Foreign Language Capacity
MT	Musical Training
NoMT	Without Musical Training
PME	Professional Musical Education

2.1.1. Children

77 participants were children between 11 and 12 years of age ($M= 11.36$; $SD = 0.48$). Within the children group 39 participants, (children NoMT), reported to have never been trained in a musical instrument for a longer period, while 38 participants (children MT) had received formal musical training for more than 2 years in a row before testing took place. In addition, the children were only trained in English as a foreign language.

2.1.2. Adolescents

The group of adolescents consisted of 171 individuals aged 13-17 years ($M= 15.64$; $SD = 1.18$). The adolescents were divided into different groups based on their musical experience and foreign language capacity. The participants were categorized as adolescents with or without musical training when they fulfilled the following criteria. The adolescents without musical training did not receive any formal musical training for any musical instrument or had not received singing lessons before testing took place. Learning the recorder in school was not considered musical training, excluding those who reported playing the recorder consistently for more than two consecutive years prior to testing. Additionally, the participants without musical training reported that they were unable to play a musical instrument and had not learned one through either formal or informal instruction. In contrast, the adolescent participants were categorized as having musical training if they had played a musical instrument regularly for more than two consecutive years prior to testing.

The participants were also distinguished according to their foreign language capacity. All adolescents received training in foreign languages. All of them received training in English. Participants were classified as adolescents with extensive spoken foreign language training and could comprehend at least 3 languages at a high level. This could mean that they were able to master two foreign languages besides their mother tongue at a B2 or C1 level, or, this included a few participants who grew up ($N=4$) with two mother tongues and spoke one or more foreign languages at a B2 or C1 level. The collection of language proficiency data was facilitated through an online questionnaire, capturing participants' self-reported language skills.

All participants were asked in the questionnaire whether they had previously received a clinical diagnosis of Attention Deficit Hyperactivity Disorder (ADHD). A subgroup reported a prior clinical diagnosis and was assigned to the ADHD group accordingly. No additional diagnostic assessments were conducted within the framework of the present study. ADHD has a worldwide prevalence of approximately 5% (Polanczyk et al. 2007), which explains the presence of individuals with ADHD in a large and heterogeneous sample. The prevalence citation is provided for contextualization only and does not reflect group assignment procedures. The ADHD group neither consisted of individuals who played a musical instrument for a longer period nor who had mastered more foreign languages besides English. According to the above description, the adolescents were divided into adolescents without musical training with no extensive foreign language training (NoMT+NoEFL; N=39), adolescents with musical training with no extensive foreign language training (MT+NoEFL; N= 31), adolescents with musical training and extensive foreign language capacity (MT+EFL; N=42), adolescents without musical training but with extensive foreign language capacity (NoMT+EFL; N= 30) and adolescents possessing ADHD (N= 29).

2.1.3. Adults

The categorization of adult participants followed a similar approach to that used for adolescents. The age group of adult participants included individuals (N=476) between the ages of 19 and 69 (M= 30.79; SD = 11.87). They were also grouped according to both their musical background and their foreign language proficiency. The participants were categorized as adults with or without musical training when they fulfilled the following criteria. Adult participants without musical training had not undergone any formal instruction in any musical instrument or had not received any singing lessons prior to the testing sessions. Learning the recorder in school was also not considered as musical training for the adult participants. Additionally, the participants without musical training reported t being unable to play a musical instrument and not having received in either formal or informal instruction. Musicians who no longer train or play instruments, often referred to as “sleeping musicians”, were excluded from this study, because they could not be classified in a meaningful category.

Adult participants were categorized as having musical training if they had played a musical instrument regularly for more than three years, including at least some practice within the last five years prior to testing time. In addition, a further subcategory of participants was introduced for the adults who were professional musicians. As professional musicians, we considered participants who had either a minimum of four years’ experience performing regularly in public as orchestra members, had completed at least six semesters of music studies, or, had worked as music educators. Furthermore, the participants were differentiated based on their foreign language proficiency. All adults underwent foreign language training. Participants were categorized as adults with extensive foreign language training if they had demonstrated proficiency in

speaking and could comprehend at least three languages at a high level. This implies that participants were considered to have extensive foreign language proficiency if they were able to master at least two foreign languages, in addition to their mother tongue, at the B2 or C1 level. Additionally, it encompassed a subgroup of participants (N=12) who grew up with bilingual backgrounds and who had achieved a B2 or C1 level in one or more foreign languages. We did not further divide the professional participants based on their language proficiency, as this would have resulted in groups that were too small. To assess group differences between professional musicians with and without extensive foreign language experience, we performed an independent *t*-Test which outlined no significant differences between the two groups. The results are provided in the supplementary material (see table S1). In addition, a subgroup of adults reported a prior clinical diagnosis of ADHD. As in the adolescent sample, inclusion in the ADHD group was based on self-reported prior clinical diagnosis collected via questionnaires. The ADHD group included neither participants with extended musical training nor participants who had mastered additional foreign languages beyond English at a high level. According to the above description, we had six different groups: adults without musical training with no extensive foreign language capacity (NoMT+NoEFL; N=73), adults with musical training with no extensive foreign language training (MT+NoEFL; N= 58), adults with professional musical education (PME; N=49); adults with musical training and extensive foreign language (MT+EFL; N=154); adults with extensive foreign language without musical training (NoMT+EFL; N= 115) and adults with ADHD (N= 27).

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2.2. Speech perception measurement

We used an adapted and short version of a previously developed speech perception task – specifically assessing auditory pattern recognition ability for unfamiliar speech (Christiner, Bernhofs and Groß 2022; Coumel et al. 2023; Groß et al. 2023). Therefore, we selected languages (Tagalog, Mandarin, Farsi, Japanese) which are rarely spoken in Europe and neither spoken, comprehended, nor learnt by the participants of this study. The perception task simulated language learning situations in which learners receive speech input lacking semantic content. This measure parallels musical aptitude assessments, which assume that the stimuli (e.g., a specific melody) are unfamiliar to the participants. During the test condition of the speech perception task, participants were instructed to listen to a sequence of speech strings, each consisting of eight different words or short phrases, then provide a response. This response was either present or absent from the preceding string that the participants had heard. Each utterance of the string is separated by a short pause of 50 milliseconds, while the response is separated from the string by a longer pause of two seconds and is further signaled by a change in screen color. After listening to a stimulus, participants were asked to indicate whether or not the response was present in the stimulus they had just heard. If the response was part of the string, participants should click the correct button. Conversely, if the response was not part of the string, participants must click the wrong button. The response may vary, encompassing either a single utterance or up to three utterances.

In cases where a response contained more than one utterance, it was scored as correct only if all the utterances from the presented string were included. The tasks consisted of 20 items, with 0.05 points awarded for each correct response, yielding a maximum possible score of 1.

The experiment was conducted online. Participants were instructed to complete the task in a quiet environment using headphones. Auditory stimuli were presented via a standardized online platform. Although listening conditions could not be fully controlled detailed instructions were provided to ensure comparable testing conditions across participants.

2.3. Questionnaire

To gather background information, we administered an online questionnaire that inquired about the music, singing, language, and educational backgrounds of the participants. The questionnaire encompassed the music and language parameters as delineated in accordance with our group divisions. Furthermore, we included questions about their self-estimated singing abilities and the average number of hours they spent singing each week. The participants had to decide which of the descriptors described their singing ability best. These were “very poor”, “poor”, “average”, “good” and “very good”. We used these singing variables as previous research outlined that all variables were associated with and reflect the participants singing ability (Christiner 2020; Coumel et al. 2023).

We also collected the educational status of the participants and of their parents. We utilized parental educational backgrounds as a measure to evaluate the socioeconomic status (SES) of the participants. Therefore, we followed the classification of UNESCO. The demarcation between low and high SES is established at the ISCED-97 level 3a, which corresponds to A-levels and/or their equivalents. This implies that participants with parents whose educational status fell below level 3a were categorized as belonging to the low SES group, whereas those at level 3a and above were categorized as high SES (OECD 1999). We followed previous research and decided on the following. If at least one of the parents possessed an educational level exceeding 3a, the participants were classified as high SES. Conversely, if both parents had completed their highest level of education below 3a, the participants were categorized as low SES. For completeness, in the adult group 16 parents did not provide their educational status. According to these descriptions, in the children’s group, 47 belonged to high SES and 30 to low SES, in the adolescents’ group, 93 belonged to the high SES and 78 to the low SES group, while 300 of the adults belonged to high SES and 160 to low SES.

2.4. Statistical analyses

Statistical analyses were carried out separately for all three groups. We performed two-way ANOVAs for all groups to provide information about the role of musical classification and SES status regarding the dependent variable, perceptual language ability. For the adult participants, we ran a second two-way ANOVA using participants' educational status as a measure of SES as a comparison. Before conducting the two-way ANOVA, we first examined the correlation between musical status and socioeconomic status (SES) to assess whether a significant association existed between these factors. The correlation analysis indicated no significant positive relationship, supporting the assumption that musical status and SES are independent factors in our dataset.

Additionally, to ensure comparable and balanced groups among adults and adolescents, a random sampling procedure was applied during group formation. This procedure produced consistent results across samples, further validating the robustness and appropriateness of the two-way ANOVA for our analysis. Furthermore, gender was assessed as t-tests. Since previous research showed that gender had no influence on the perceptual language measures (Christiner 2020; Coumel et al. 2023; Groß et al. 2023), we provided them only in the supplementary material for transparency reasons (see table S2).

Additionally, we conducted correlational analyses between the speech perception measure and the singing variables, specifically, singing hours and singing self-estimation. Previous research has indicated an association between singing and foreign language pronunciation skills. However, we did not observe a relationship between singing variables and perceptual foreign language skills in previous study (Christiner, Bernhofs and Groß 2022).

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3. RESULTS

3.1. Statistical results children

A two-way ANOVA was performed to provide information about the role of musical classification and SES status with regard to the dependent variable the perceptual language ability (see figure 1). The results of the two-way ANOVA revealed a significant main effect for the language perception score, showing a group difference between the participants when they are divided into high (N= 47) and low SES (N= 30); ($F(3, 76) = 7.97$, $p = 0.006$, partial $\eta^2 = 0.24$: High SES group ($M = 0.61$, $SD = 0.12$) than for the low SES group ($M = .58$, $SD = 0.12$). There was also a significant main effect for musical classification ($F(3, 76) = 7.11$, $p = 0.011$, partial $\eta^2 = 0.22$). The results revealed that children with musical training (children MT; $M = 0.60$, $SD = 0.019$); performed significantly better than the children without musical training (children NoMT; $M = 0.54$, $SD = 0.018$). However, there was no significant interaction between the musical classification of the children and the SES status ($F(3, 76) = 0.19$, $p = 0.66$; partial $\eta^2 = 0.007$).

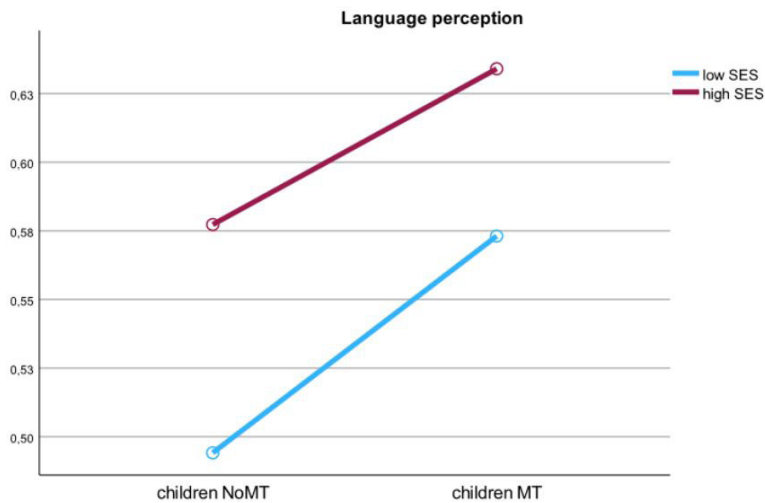


Figure 1 illustrates the mean values of the language perception measurement of the two groups (children with and without musical training) divided into high and low SES.

3.2. Statistical results adolescents

The statistical analyses of the adolescents included a two-way ANOVA to assess group differences for the music and language classification as well as the SES status (see figure 2). The results of the two-way ANOVA revealed a non-significant main effect for the language perception score, showing a group difference among the participants when they are divided into high (N= 93) and low SES (N= 78); ($F(9, 170) = 2.5, p = 0.117$, partial $\eta^2 = 0,006$). Despite the non-significant result, the means are higher for the High SES group (M = 0.64, SD = 0.12) than for the low SES group (M = .59, SD = 0.12).

There was, however, a significant main effect for musical classification ($F(9, 170) = 8.81, p = 0.001$, partial $\eta^2 = 0.32$). As we had unequal group sizes, Gabriel-corrected post-hoc analysis was applied (see table S3). The results revealed that adolescents with musical training and no extensive foreign language training performed best (MT+NoEFL; M = 0.67, SD = 0.11), followed by adolescents with musical training and extensive foreign language capacity (MT+EFL; M = 0.66, SD = 0.12), adolescents without musical training and with extensive foreign language capacity (NoMT+EFL; M = 0.64, SD = 0.10), adolescents without musical training and no foreign language training (NoMT+NoEFL; M = 0.57, SD = 0.12) and individuals possessing ADHD (ADHD; M = 0.52, SD = 0.11). The difference was only significant between the groups with and without musical training. However, there was no significant interaction between the musical classification and the SES status ($F(9, 170) = 0.86, p = 0.49$; partial $\eta^2 = 0.04$).

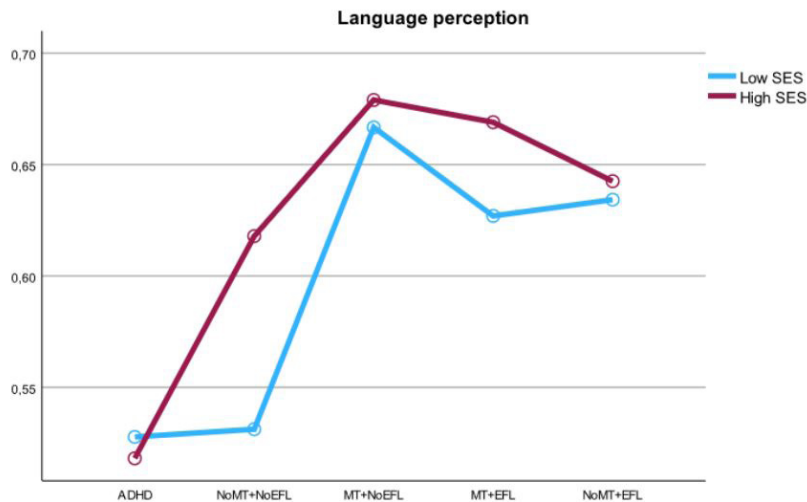


Figure 2 illustrates the mean values of the language perception measurement of the adolescents separated into high and low SES.

3.3. Statistical results adults

The statistical analyses of the adults follows the same rational idea than what we did for the adolescents. First, we performed a two-way ANOVA to assess group differences for the music and language classifications as well as the SES status based on parental education. In addition, we performed a second two-way ANOVA in which we replaced the parental SES of the participants by the participants own SES status to be able to compare both (compare with section 4 and figure S1 in the supplementary material).

The results of the two-way ANOVA revealed a significant main effect for the language perception score, showing a group difference among participants when they are divided into high and low SES ($F(11, 459) = 4.97, p = 0.026, \text{partial } \eta^2 = 0.11$: High SES ($M = 0.68, SD = 0.12$ and low SES ($M = 0.64, SD = 0.12$).

There was also a significant main effect for musical classification ($F(11, 459) = 12.32, p = 0.001, \text{partial } \eta^2 = 0.23$). As we had unequal group sizes, Gabriel-corrected post-hoc analysis was applied (see table S4). The results revealed that adults with professional musical education performed best (PME; $M = 0.73, SD = 0.12$), followed by the adults with extensive foreign language and musical training (MT+EFL; $M = 0.70, SD = 0.11$) the adults with musical training with no extensive foreign language training (MT+NoEFL; $M = 0.69, SD = 0.10$), the adults with extensive foreign language without musical training (NoMT+EFL; $M = 0.64, SD = 0.10$), the adults without musical training with no extensive foreign language training (NoMT+NoEFL; $M = 0.62, SD = 0.14$) and the ADHD group (ADHD; $M = 0.54, SD = 0.10$). The difference was significant comparing the ADHD group to all other groups. In addition, the difference was also significant between the groups with and without musical training. However, there was no significant interaction between the musical classification and the SES status ($F(9, 459) = 0.59, p = 0.71; \text{partial } \eta^2 = 0.14$).

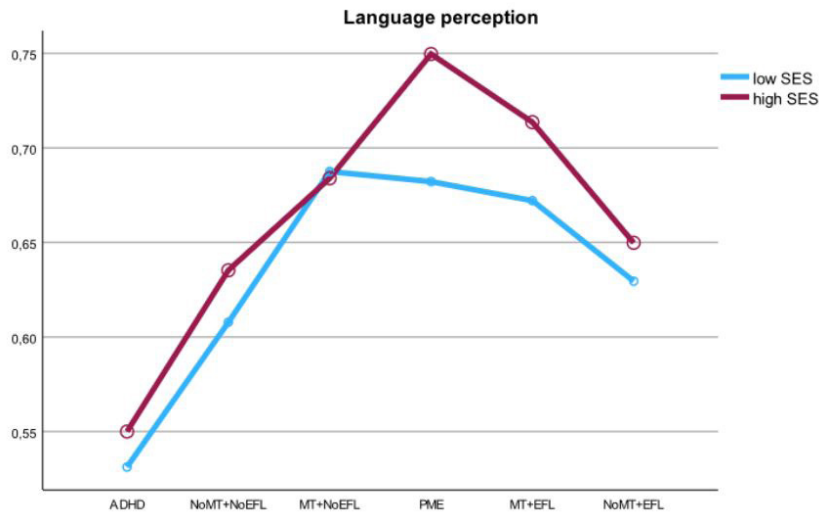


Figure 3 illustrates the mean values of the language perception measurement of the adult groups separated into high and low SES. Note that the PME group was not divided into individuals with and without EFL as the group would have been too small. We provided a t-test in the supplement showing that within the PME group, no differences between individuals with and without EFL were detected (see supplement table S1).

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3.4. Correlations of the language and singing variables for all groups

Previous studies have suggested a link between singing and the ability to pronounce foreign languages, but in previous research we did not find a link between singing factors and perceptual foreign language ability. This is why we also performed correlations between the language perception variable and the singing self-estimation variable and the amount individuals sang on average a week (see table 2).

Table 2 shows the correlations of the language perception measurement and the singing variables for the children group

	Singing hours per week	Self estimation Singing
Perceptual language ability		
children	0.032	-0.025
adolescents	0.078	0.066
adults	-0.001	0.049
Singing hours per week		
children	1	0.306**
adolescents	1	0.365**
adults	1	0.439**

* $p < 0.05$ (uncorrected, two-tailed). ** $p < 0.001$ (uncorrected, two-tailed).

4. DISCUSSION

The present study intentionally adopted an integrative, multifactorial design to examine the relative contribution of musical training, foreign language capacity, socio-economic status (SES), and ADHD within a unified framework. While each of these predictors could be investigated independently, our aim was to assess their comparative and combined influence on unfamiliar speech perception across age groups.

The outcomes of our study reveal that across the lifespan, the ability to discriminate against unfamiliar speech material is influenced by factors such as musical training/status, foreign language ability, and socioeconomic status (SES). In addition, as hypothesized, neither the amount of singing nor self-estimated singing ability was associated with speech perception performance. In light of the findings of this study, we will discuss the following aspects in more detail. First, we will shortly discuss singing and speech perception (Q4). Second, we will discuss the benefits of perceptual musical skills from the perspective of musicians and individuals with ADHD (Q1 and Q3). Third, we will discuss the impact of speaking more languages on a high level and its advantage related to the ability to discriminate against unfamiliar languages (Q2). Fourth, we will discuss the influence of SES on language ability also in the context of critical age factors (Q5).

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Singing Variables and Speech Perception (Q4)

We included two singing variables in the research design, a self-estimation variable, and the amount of singing on average in a week. While musical training/status has been a predictive variable for explaining individual differences in unfamiliar speech perception, we observed that singing variables appear to be less effective in predicting perceptual language variables such as auditory pattern recognition. Previously, proficient singers showed enhanced musical discrimination and pronunciation skills, but no improvement in language perception (Christiner, Bernhofs and Groß 2022). Similar findings exist for professional musicians. Singers outperformed instrumentalists in foreign language pronunciation (Christiner and Reiterer 2015) showing that singing is a highly sensory training transferable to other forms of vocalization. As hypothesized (Q4), singing variables showed no association with speech perception. This null result carries important educational implications: while most music and language training prioritizes perceptual skills, curricula should equally emphasize productive abilities to foster comprehensive development.

Musical Training and ADHD (Q1 & Q3)

Perceptual studies examining the intersection of music and language have revealed that musical training can enhance both speech processing and speech perception (Besson, Chobert and Marie 2011; François et al. 2013; Kraus and Chandrasekaran 2010; Thompson, Schellenberg and Husain 2004). The present study confirms musical

training's perceptual benefits for unintelligible foreign language material. Musically trained participants across all age groups outperformed controls in these language perception tasks. As expected, ADHD participants (adolescents and adults) showed reduced performance in language perception tasks compared to controls. Previous neurophysiological research has demonstrated that individuals with ADHD may show atypical auditory processing patterns, including alterations in early auditory evoked responses such as the P1 component (Christiner and Serrallach et al. 2022; Groß et al. 2022; Serrallach et al. 2016). These findings indicate differences in early-stage auditory processing in clinical populations. Although no neurophysiological measures were collected in the present study, the lower behavioral performance observed in the ADHD group is consistent with prior reports of auditory processing differences. However, the current data do not allow direct conclusions regarding underlying neural mechanisms (Serrallach et al. 2016).

Foreign Language Capacity (Q2)

The adolescent and adult participants were also divided into musically naïve participants with and without extensive foreign language capacity. Through extensive foreign language training, we mean that they spoke at least three languages at an advanced level. (Q2). The findings of the adolescents have shown that musically naïve participants with extensive foreign language capacity could not be distinguished from the two groups who were musically trained, while in the adult group, the professional musicians and the musically trained participants with extensive foreign language capacity performed significantly better than the adult group without musical training and extensive foreign language capacity (please compare figures 2 and 3 and tables S3 and S4).

It could be suggested that extensive foreign language and musical training both have a significant effect on the ability to discriminate against unfamiliar languages. However, the impact of extensive foreign language experience seems more pronounced during adolescence, whereas in adulthood, musical training appears to be the stronger predictor of such perceptual abilities. This finding also corresponds to the literature available. Scholars have proposed that phonetic ability is the only linguistic capacity subject to a critical period, typically declining after puberty (Moyer 2014). It is widely accepted that multilingual speakers are accustomed to perceiving and differentiating between diverse phonemes, which benefits them when encountering unfamiliar languages (Hell and Mahn 1997; Kaushanskaya and Marian 2009; Papagno and Vallar 1995). Individuals who speak more foreign languages are exposed to a broader range of acoustic features across languages. This exposure can make them more familiar with various sound patterns and accents, allowing them to adapt more quickly to novel phonetic structures (Spinu, Hwang and Vasilita 2023; Tremblay and Sabourin 2012). Thus, foreign language learning may exert an effect on perceptual skills, among others, comparable in strength to that of musical training during adolescence.

Although it is generally accepted that phonetic ability diminishes after puberty, a low number of individuals can reach native-like foreign language proficiency when they are adults (Selinker 1972). Professional musicians may fall into this category. Comparable to children and adolescents, adult musicians seem to retain a certain plasticity to adapt novel phonetic structures rather fast (Christiner 2020; Christiner and Reiterer 2013; Christiner and Reiterer 2015). Our findings of overlapping musical and speech perception abilities across the lifespan align with neuroscience evidence showing that lifelong musical training preserves musicianship-specific cortical characteristics – such as enhanced auditory cortex gyrification and broader network activation during tone perception – despite age-related atrophy (Rus-Oswald et al. 2022). Musicians also exhibit reduced age-related decline compared to non-musicians, particularly in auditory processing functions relevant to speech and music perception (Fostick 2019; Hanna-Pladdy and MacKay 2011). These findings suggest that musical training may help maintain elaborate perceptual skills across the lifespan.

Research has shown that engaging in active music-making encompasses a wide range of neural processes, including perception, cognition, brain connectivity, and behavior (Kraus and Chandrasekaran 2010; Tierney, Krizman and Kraus 2015) processing (Serrallach et al. 2016). While such findings provide an important theoretical framework for interpreting behavioral advantages in musicians, the present study was limited to behavioral measures and does not allow direct conclusions regarding neural normalization or neurological mechanisms.

Socioeconomic Status and Developmental Considerations (Q5)

Parental educational background served as our SES indicator, while participants' own educational attainment was analyzed separately. Parental SES significantly predicted language ability differences (high vs. low SES), whereas participants' educational status did not. SES demarcation followed ISCED-97 level 3a (A-levels equivalents), typically attained by adulthood. The findings show that family SES predicts language abilities. Studies have shown that higher SES of mothers and caretakers are positive predictors for language ability (Huttenlocher et al. 2010). Individuals belonging to low SES show poorer performance in language ability (Calvo and Bialystok 2014). The findings of our study provide similar information. While the SES differences were not significantly different in the adolescent group, those with high SES tended to score higher on average than those with low SES. This trend held true for the children and adults, with individuals from higher SES backgrounds consistently outperforming those with lower SES. Our study corroborates the findings of previous studies that provided evidence that the impact of socioeconomic disparities on language abilities may persist well into adulthood and affect academic achievement (Hoff 2013).

Our study also has limitations, and further research is needed to give more precise answers about the effect of foreign language capacity and musical ability. While SES appears to play a major role in early childhood and adulthood, this effect was less clear

in our adolescent sample. Future studies should examine how early socioeconomic factors influence foreign language learning success in adulthood. Musical training was associated with beneficial effects across all age groups, suggesting it may be relevant across the lifespan. However, we cannot determine whether this reflects ongoing training, early acquired capacity, or both. Therefore, future research should also include a subgroup on “sleeping musicians (individuals who stopped training many years ago)” to address this in more detail. In addition, future studies with children should include individuals raised bilingually or multilingually to examine whether extensive early language exposure yields effects comparable to musical training. Future research using longitudinal designs would be required to determine whether the observed differences reflect developmental change over time.

5. CONCLUSIONS

Our study demonstrates that socioeconomic status (SES), musical training, and – to a lesser extent – foreign language proficiency is associated with speech perception abilities from childhood through adulthood, while singing parameters play a minor role. Given the cross-sectional nature of the design, the findings should not be interpreted as evidence of developmental trajectories. Musical training showed consistent associations with speech perception across all age groups. Extensive foreign language knowledge appeared particularly relevant during adolescence.

Compared to adolescents, musical training appeared to exert a more pronounced influence on unfamiliar speech perception in adulthood than foreign language capacity alone. Furthermore, the lower performance observed in adolescents and adults with ADHD suggests that differences in auditory processing may play a role in early stages of unfamiliar language perception.

These findings support the notion that individual differences in auditory expertise and cognitive processing capacities contribute to variability in unfamiliar speech perception. While musical training may be associated with enhanced perceptual sensitivity, individuals with clinically reported attentional and auditory processing difficulties may encounter additional challenges during the initial stages of foreign language learning.

However, as the present study relied exclusively on behavioral measures, interpretations regarding shared or overlapping neural mechanisms remain theoretical and require future investigation using combined behavioral and neurophysiological approaches.

Supplementary Materials: Table S1: independent t-tests for the perceptual language ability with and without extensive foreign language capacity for the adults with professional music education.; Table S2: independent t-tests for the perceptual language ability and gender for children, adolescents and adults; Tables S3 and S4: Gabriel-corrected post-hoc analysis for adolescents and adults; Figure S1: mean values of the language perception measurement of the adolescents separated into high and low SES.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of the Medical Association of Riga (Latvia) 2-P - EK-4/3/2022.

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Supplementary Materials: Table S1: independent t-tests for the perceptual language ability with and without extensive foreign language capacity for the adults with professional music education.; Table S2: independent t-tests for the perceptual language ability and gender for children, adolescents and adults; Tables S3 and S4: Gabriel-corrected post-hoc analysis for adolescents and adults; Figure S1: illustrates the mean values of the language perception measurement of the adolescents separated into high and low SES (personal education status).

1. Independent t-Test for the perceptual language ability with and without extensive foreign language capacity for the adults with professional music education

Table S1 shows the t-tests for perceptual language ability with (EFL) and without extensive foreign language capacity (NoEFL) for adults with professional music education (PME).

Variables	Group comparisons and Means	Mean Difference	<i>t</i>	df	<i>p</i>
Perceptual language ability	EFL (<i>M</i> = 0.74; <i>SD</i> = 0.13) NoEFL (<i>M</i> =0.74; <i>SD</i> =0.13)	-0.00	-0.056	47	0.96

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2. Independent t-Test for Gender

Table S2 shows the t-tests of the perceptual language ability and gender for children, adults and adolescents.

Variable: Perceptual language ability	Group	Group comparisons and Means	Mean Difference	<i>t</i>	df	<i>p</i>
	children	female (<i>M</i> = 0.59; <i>SD</i> = 0.13)	-0.05	-1.73	75	0.87
		male (<i>M</i> =0.55; <i>SD</i> =0.10)				
	adolescents	female (<i>M</i> = 0.60; <i>SD</i> = 0.13)	0.02	1.08	214	0.28
		male (<i>M</i> =0.62; <i>SD</i> =0.12)				
	adults	female (<i>M</i> = 0.67; <i>SD</i> = 0.13)	-0.00	-0.21	474	0.84
		male (<i>M</i> =0.66; <i>SD</i> =0.12)				

3. Gabriel post-hoc analyses

Table S3. Group differences in language perception capacity across the adolescent groups of this investigation.

Group	Means and standard deviation	Post-hoc comparisons	Mean Difference	Std. Error	p	95% Confidence Interval	
						Lower Bound	Upper Bound
ADHD	M = 0.52; SD = 0.11	vs. NoMT+NoEFL	-0.05	0.03	= .659	-0.01	0.14
		vs. MT+NoEFL	-0.15	0.03	< .001	-0.23	-0.07
		vs. MT+EFL	-0.13	0.03	< .001	-0.21	-0.06
		vs. NoMT+EFL	-0.12	0.03	< .001	0.03	0.19
NoMT+NoEFL	M = 0.57 SD = 0.12	vs. MT+NoEFL	-0.10	0.03	= .004	-0.18	-0.22
		vs. MT+EFL	-0.08	0.03	= .018	-0.16	-0.01
		vs. NoMT+EFL	-0.07	0.03	= .135	-0.14	0.01
MT+NoEFL	M = 0.67; SD =0.11	vs. MT+EFL	0.02	0.03	.999	-0.06	0.09
		vs. NoMT+EFL	0.04	0.03	.865	-0.04	0.11
MT+EFL	M = 0.66; SD =0.12	vs. NoMT+EFL	0.02	0.02	.998	-0.05	0.09
NoMT+EFL	M = 0.64; SD = 0.10						

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PME = professional music education; EFL = with extensive foreign language capacity; NoEFL = without extensive foreign language capacity (only english as foreign language); MT = with musical training; NoMT = without musical training;

Table S4. Group differences in language perception capacity across the adult groups of this investigation.

Group	Means and standard deviation	Post-hoc comparisons	Mean Difference	Std. Error	p	95% Confidence Interval	
						Lower Bound	Upper Bound
ADHD	M = 0.54; SD = 0.10	vs. NoMT+NoEFL	-0.08	0.03	= .027	-0.15	-0.01
		vs. MT+NoEFL	-0.14	0.03	< .001	-0.22	-0.07
		vs. PME	-0.18	0.03	< .001	-0.26	-0.11
		vs. MT+EFL	-0.16	0.02	< .001	-0.22	-0.09
		vs. NoMT+EFL	-0.10	0.02	< .001	-0.17	-0.03
NoMT+NoEFL	M = 0.62 SD = 0.14	vs. MT+NoEFL	-0.06	0.02	= .022	-0.12	-0.01
		vs. PME	-0.11	0.02	< .001	-0.17	-0.05
		vs. MT+EFL	-0.08	0.02	< .001	-0.13	-0.03
		vs. NoMT+EFL	-0.02	0.02	.826	-0.07	0.03
MT+NoEFL	M = 0.69; SD =0.10	vs. PME	-0.04	0.02	.557	0.01	0.12
		vs. MT+EFL	-0.02	0.02	.997	-0.07	0.03
		vs. NoMT+EFL	0.04	0.02	.234	-0.01	0.10
PME	M = 0.73; SD = 0.12	vs. MT+EFL	0.03	0.02	.889	-0.08	0.03
		vs. NoMT+EFL	0.09	0.02	< .001	0.03	0.14
MT+EFL	M = 0.70; SD =0.11	vs. NoMT+EFL	0.06	0.01	< .001	0.02	0.10
NoMT+EFL	M = 0.64; SD = 0.10						

PME = professional music education; EFL = with extensive foreign language capacity; NoEFL = without extensive foreign language capacity (only english as foreign language); MT = with musical training; NoMT = without musical training; PME = with professional music education

4. Two-way ANOVA with high and low SES based on the participants educational status

A two-way ANOVA was performed to provide information about the role of musical classification and SES status of the participants according to their personal educational status with regard to the dependent variable of perceptual language ability. This two-way ANOVA was provided to show the contrasts to the parental education.

In marked contrast to the two-way ANOVA based on the educational status of the parents, when we use the participants highest level of education and use the cut off value of level 3a, the SES distinction is non-significant. ($F(11, 475) = 0.34, p = 0.56$, partial $\eta^2 = 0.008$: High SES ($M = 0.67, SD = 0.13$ and low SES ($M = 0.66, SD = 0.12$).

The results of the two-way ANOVA revealed a significant main effect for the musical classification ($F(11, 459) = 17.63, p = 0.001$, partial $\eta^2 = 0.29$). The results revealed that adults with professional musical education performed best (PME; $M = 0.74, SD = 0.13$), followed by the adults with extensive foreign language and musical training (MT+EFL; $M = 0.70, SD = 0.11$), the adults with musical training with no extensive foreign language training (MT+NoEFL; $M = 0.68, SD = 0.10$), the adults with extensive foreign language without musical training (NoMT+EFL; $M = 0.64, SD = 0.10$), the adults without musical training with no extensive foreign language training (NoMT+NoEFL; $M = 0.60, SD = 0.14$) and the ADHD group (ADHD; $M = 0.54, SD = 0.10$). However, there was no significant interaction between musical classification and SES status ($F(9, 475) = 0.59, p = 0.71$; partial $\eta^2 = 0.014$).

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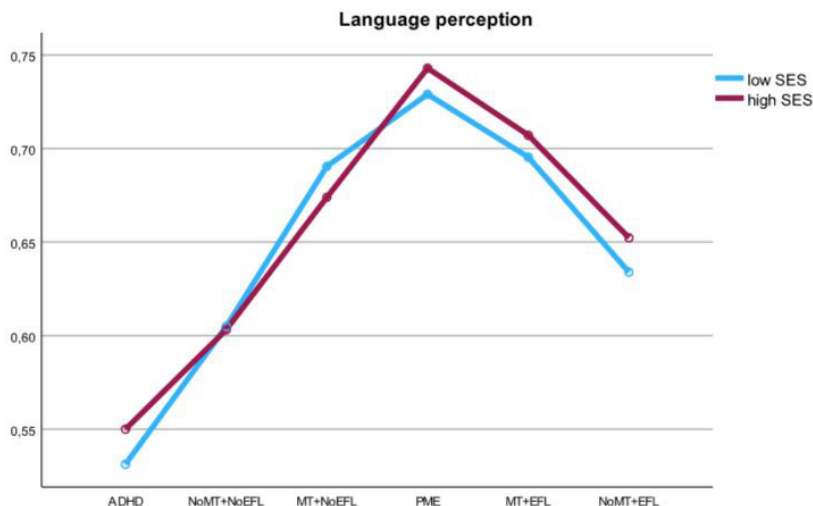


Figure S1 illustrates the mean values of the language perception measurement of adolescents separated into high and low SES (personal education status).