VOWEL DISCRIMINATION ABILITIES IN QUEBEC FRENCH SCHOOL-AGED CHILDREN

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Résumé

Bien que la perception auditive de la parole soit déjà bien développée dès la naissance, elle se raffine et se spécifie durant l'enfance et le début de l'adolescence. De nombreuses études ont documenté le développement perceptuel auditif précoce, mais très peu de données ont été obtenues sur les changements qui surviennent dans l'enfance. Cette étude a pour objectif d'étudier le développement de la discrimination de voyelles chez les enfants francophones du Québec d'âge scolaire. Des voyelles synthétisées qui s'opposent selon la dimension d'aperture et selon la dimension d'arrondissement ont été utilisées comme stimuli lors d'un test de discrimination. Quarante-neuf enfants âgés de 6 à 10 ans et douze adultes ont participé à la tâche. Les scores maximaux de discrimination des voyelles et les frontières catégorielles sont significativement différents entre 7 et 9 ans, ce qui suggère des changements dans le traitement auditif de la parole.

Mots clefs : perception de la parole, voyelles, développement de la parole

Abstract

Although auditory perception develops in infancy, it continues to mature until mid-adolescence. Many studies have documented early auditory perceptual development, yet very little is known about changes that occur in childhood. This study aimed to investigate the development of vowel discrimination in school-aged Quebec French-speaking children. Synthesized vowels contrasting along height and rounding were used as stimuli in a discrimination test given to 49 children aged 6 to 10 years old and twelve adults. Peak vowel discrimination scores and category boundaries shifted between 7 and 9 years of age, which suggests changes in speech processing.

Keywords: speech perception, vowels, speech development

1 Introduction

Speech acquisition is a complex process that entails the maturation of several biological systems. One of the challenges that newborns face is learning the phonemic categories of their native language. Those categories are formed through an important mechanism by which different instances of a sound are grouped into single perceived categories [1]. This mechanism, referred to as categorical perception, requires complementary perceptual skills, which include identification or labelling (the ability to link a sound to an appropriate phonemic label) and discrimination (the ability to distinguish between two sounds across categories) of sounds [2]. Several studies have shown that during the first months of life, infants undergo perceptual narrowing, which means that they gradually lose the ability to perceive contrasts between phonemic categories that do not belong to their native language (for instance: [3, 4]). Despite this achievement, a 1-year-old's ability to perceive phoneme categories in his or her native language is not yet adult-like. Indeed, a growing body of evidence suggests that infants and young children do not perform as well as adults in phonemic categorization tasks or discrimination tasks [5]. For instance, the slope of the identification function between pairs of phonemes (in an identification test) becomes steeper with age, reflecting better abilities to define phonemic categories in older children, compared to younger ones. This was found for the voice-onset time continuum in 2- to 14-year-old English- and French-speaking children [6], 2- to 6-year-old children [7], 6- to 12-year old children [8], and 5- to 10-year-old children [9]. This developmental trajectory may be related to the different cues used by children versus adults to identify phonemes. In a study of categorical perception of voice-onset time in French-speaking children and adolescents, Medina et al. (2010) [10] noted that the steepness of the identification function increased between 9 and 17 years of age, although no boundary shift was found.

Similarly, peak discrimination scores (in a discrimination test) also increase with age. For example, it was shown that low-frequency tone discrimination in 5-year-old children was poorer than in 7- and 9-year-old children, even after extensive training [11]. In a series of studies on consonant perception by children and adults, Nittrouer and col-

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leagues [12-15] showed, through labelling and discrimination tasks, that 3- to 8-year-old children were better at discriminating dynamic cues than static cues, while the reverse was observed in adults. Boundary shifts between phonemes have also been shown to occur as a function of age [6, 16-18]. For example, Flege and Eefting (1986) [18] have reported that 9-year-old children did not display adult-like performance when perceiving the /t/ vs. /d/ contrast. Taken together, these results suggest that speech perception continues to evolve until early adolescence. The exact origin of these changes is still debated, and they probably involve cognitive, attentional, and language exposure factors, to name just a few.

According to Werner (2007) [19], the development of postnatal auditory processing involves three stages. The first stage lasts until 6 months old and concerns basic neural encoding processing, whereas the second stage extends from then until the start of the school years and allow infants and children to use more specific characteristics of speech sounds. The third stage begins when children start school and ends at age 8 or 9 (although some authors report some perceptual immaturity even in 12-year-olds). During the third stage, children fine-tune their auditory perception abilities. Werner's auditory-processing model is consistent with Burnham’s (2002) [5] three-stage model of speech perception. Indeed, as soon as children learn grapheme-to-phoneme regularities of their language between the 1st grade and 5th grade (orthographic stage), the ability to perceive native contrast improves, whereas their ability to perceive nonnative contrasts deteriorates, with a marked dip at age 6 [20].

As can be seen by the increasing number of studies in this field, there is a growing interest in children's speech perception. However, most of the above-mentioned studies were conducted on consonant contrasts, and little is known about the effects of developmental changes on vowel-discrimination abilities in school-aged children. Vowel contrasts are known to be perceived in a more continuous manner than consonant contrasts. Nevertheless, developmental changes in vowel perception have been reported in some studies [13, 21-23]. For example, a study on the development of perceived French oral vowels investigated how 4- to 8-year-old children and adults labelled synthesized vowels [24] and showed that the children displayed different category boundaries and less steep identification slopes compared to the adults. To further investigate age-related differences in vowel discrimination abilities, the current study aimed to examine the ability of Quebec-French speaking 6- to 10-year-old children and adults to discriminate between two vowel pairs (with contrasting height and rounding).

2 Method

2.1 Participants

The study has been approved by the Université du Québec à Montréal’s Institutional Review Board. Forty-nine children between 6 and 10 years of age were recruited: nine 6-year-olds (four males, five females), eleven 7-year-olds (five males, six females), nine 8-year-olds (four males, five females), eight 9-year-olds (four males, four females) and eight 10-year-olds (four males, four females). Twelve adults aged between 25 and 41 years-old (six males, six females) were also recruited. The participants were all native Quebec French speakers with no history of any language, speech or hearing disorder (self-report or as reported by parents and school teachers). In order to be included in the study, participants had to be native speakers of Quebec French and had to use Quebec French at home. The children attended public school in the greater Montreal area and were in kindergarten to grade 6. All participants were tested for pure-tone detection threshold using an adaptive method (Detection Threshold < 25 dB HL at 250, 500, 1000, 2000, 4000, and 8000 Hz).

2.2 Stimuli and procedure

Two sets of five-formant vowels ranging from /i/ to /e/ and from /e/ to /ø/ were synthesized using the variable linear articulatory model (VLAM, [25])[1]. Those two continua corresponded to two phonological features along which French oral vowels are produced: height (/i/ vs. /e/) and rounding (/e/ vs. /ø/). The formant values of the end-point stimuli for each of the two continua, listed in Table I, were those used in previous auditory perceptual studies with similar synthesized stimuli [26, 27]. The formant bandwidths for the five formants were calculated based on an analogue simulation [28]. For the /i/ vs. /e/ continuum, five stimuli were created between the end-points at equally stepped F1, F2, and F3 distances, as shown in Table 1 (for a total of seven stimuli). The rounding continuum, corresponding to the /e/–/ø/ dimension, was represented by eleven stimuli, equally stepped in F1, F2, F3, and F4 (see Table 1). A cascade formant synthesizer was excited by a glottal waveform generated by the Liljencrants-Fant source model. The resulting signal was digitized at 22 kHz and was 400 ms long. A fall-rise amplitude contour was applied to the signal. The F0 values were 110 Hz.

Table 1: Formant and bandwith values of endpoint stimuli used in the perceptual task.

Vowel	F1	F2	F3	F4	F5	B1	B2	B3	B4	B5
/i/	236	2062	3372	3550	4000	78	13	61	154	154
/e/	364	1922	2509	3550	4000	48	55	60	50	100
/ø/	364	1592	2069	3000	4000	88	40	19	19	19

Synthesized vowel stimuli from the two continua were presented to each participant in discrimination tasks. A classic AXB design was used. In this task, for a given continuum, A and B represent two stimuli that are one step apart on the synthesized continuum, and X is the same as

[1]The /e/ vs. /ɛ/ pair was also tested but was not analyzed because of its particular phonological status in Quebec French.

either A or B. After each AXB triad was played, the participant had to decide whether the second stimulus (X) was the same as the first stimulus (A) or the third stimulus (B). The interstimulus interval (interval between two triads) was 500 ms. Each triad was also presented in BXA form, where the order of the first and the third stimuli was reversed. Each triad was repeated three times, in each order (AXB and BXA), yielding a total of six repetitions for a given pair of stimuli (A and B). All stimuli were randomized across speakers and presented via headphones (AudioTechnica Profesionnal, ATH-M50x), at an intensity level of 65 dB (as measured by a GalaxyAudio sonometer). Adult participants indicated their response by clicking on a computer screen with a mouse. The children were asked to tell the experimenter if the first two or the last two sounds were identical, and the experimenter then clicked on the corresponding answer. A practice trial was conducted with all participants. The experiment started when they fully understood the task.

2.3 Data analyses

For each participant and vowel pair, percent correct discrimination scores were calculated. The highest percent correct discrimination score was extracted and considered as the peak discrimination score, for each participant and each stimulus continuum. Since the distribution of residuals, in percent, was right-skewed (non-normal), the data were log-transformed. The Shapiro-Wilk test suggested that the transformation was efficient and that the resulting log-based distributions were normal ($p=0.445$ for /i/ vs. /e/ and $p=0.100$ for /e/ vs. /ø/). The stimulus pair at which the peak discrimination score occurred was also extracted and corresponded to the category boundary. The effect of speaker age (6, 7, 8, 9, 10, or adult) on peak discrimination score and category boundary was assessed in a linear mixed effects model using the *lme4* [29] package implemented in R (R Core Team, 2012). Speaker age was the fixed factor. As random effects, intercepts for participants were entered. P-values were obtained by likelihood ratio tests of the full model with the effect in question compared with the model without the effect in question. For significant interactions, post-hoc tests were conducted using the *glht* function of the *multcomp* package (using the Bonferroni correction for multiple comparisons) [30].

3 Results

Log-transformed peak discrimination scores are presented for both vowel continua in Figure 1. Data were averaged within speaker groups. Regarding the height continuum (/i/ vs. /e/, blue lines), a significant effect of speaker group was found ($\chi^2(5)=9.12$; $p<0.001$). Post-hoc tests showed that peak discrimination scores did not significantly differ between the 6-year-old, 7-year-old, and 8-year-old groups of children. However, the peak discrimination scores were significantly lower in the 9-year-olds than in the younger or older groups ($p<0.001$). There was no significant difference in this outcome between the 10-year-old children and adults. A similar significant effect of speaker group on peak discrimination score was also found for the rounding continuum (/e/ vs. /ø/, red line) ($\chi^2(5)=11.96$; $p<0.001$), with 7-year-old and 8-year-old children having significantly lower peak discrimination scores than either 6-year-olds or older participants. Interestingly, for both vowel continua, peak discrimination scores did not significantly differ between 10-year-olds and adults.

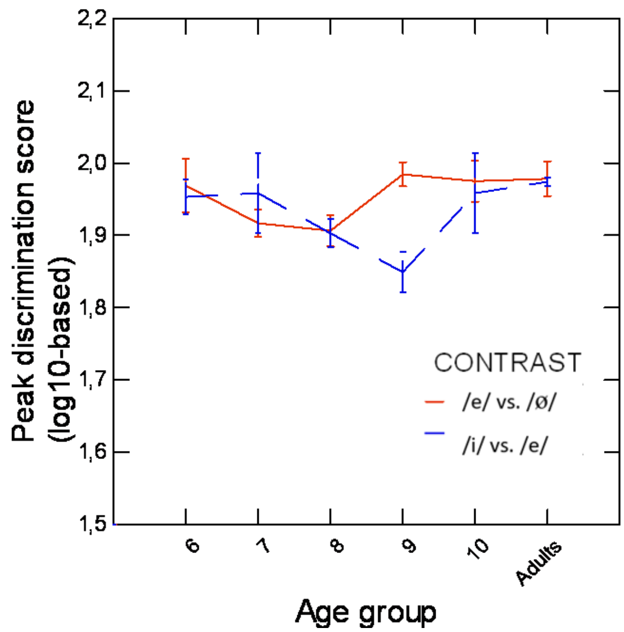

Figure 1: Average log-transformed peak discrimination score (log$_{10}$-based) for each age group. Data corresponding to the /e/ vs. /ø/ contrast are depicted in red, whereas data corresponding to the /i/ vs. /e/ contrast correspond to the blue lines. Error bars are standard errors.

Turning now to the category boundary along the height and rounding features, as can be observed in Figure 2, a shift in category boundary occurred for both contrasts between 7 and 10 years of age. Note that in Figure 2, y-axis values refer to stimulus pairs, along each continua. For the height dimension (/i/ vs. /e/, red line), in the 8-year-old children, there was a significant shift of category boundary compared to the younger and older groups ($\chi^2(5)=11.21$; $p<0.001$). The category boundary between /e/ and /ø/ was also significantly shifted in 9-year-olds compared with 10-year-olds ($\chi^2(5)=11.86$; $p<0.001$). As was the case for the values of peak discrimination score, no significant difference in category boundary along both vowel dimensions was found between the 10-year-olds and adults.

4 Discussion

The current study was designed to investigate the effect of age on the discrimination of two phonemic vowel contrasts in Quebec French: the contrast between /i/ and /e/ (height) and the contrast between /e/ and /ø/ (rounding). The results suggest that a perceptual reorganization occurs between ages 7 and 9. Indeed, concerning peak discrimination scores,

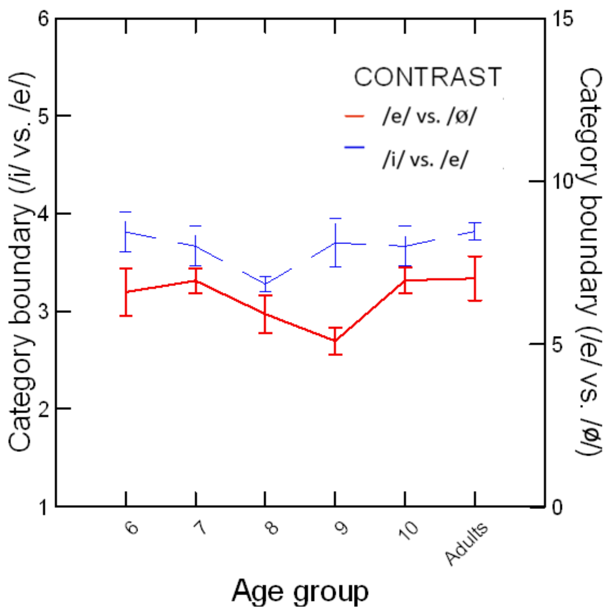

Figure 2: Average category boundary for each age group. Data corresponding to the /e/ vs. /ø/ contrast are depicted in red, whereas data corresponding to the /i/ vs. /e/ contrast correspond to the blue lines. Error bars are standard errors.

lowest values were found at 9 years of age for the height contrast, and at 7 and 8 years of age for the rounding contrast. The category boundary corresponding to these peak discrimination values also shifted between age 6 and 10 (at age 8 for height and age 9 for rounding). However, 10-year-olds and adults had similar values for peak discrimination scores and category boundary. It has to be noted, however, that for both peak discrimination score and category boundary, at 6-year-old, children had already reached values similar to the 10-year-old and the adult groups.

This pattern of results highlights the complex refinement of speech processing that occurs during the school years. Of note, the fact that discrimination performance along both vowel contrasts continued to mature until 10 years of age is consistent with previous work on consonant discrimination. Furthermore, as shown by Burnham's work [5, 20], as children enter the orthographic phase of native speech perception, their speech perception performance of nonnative pairs of sounds decreased between 2 and 6 years old and then increased in adulthood.

In the current study, several factors may explain this developmental trajectory, where specific higher-level speech processing abilities develop between 7 and 9 years of age. First, as children acquire lexical knowledge and refine their cognitive abilities, their perceptual phonemic targets become more flexible, so that they develop the ability to perceive speech in their native language that is produced with an unfamiliar accent [31]. A growing body of recent evidence also suggests that the ability to perceive speech in a language that is produced with an unfamiliar accent (for example, indexed by word recognition rates) develops over many years [32-35] and is not yet mature at 12 years of age ([31]). This new capacity likely influences perceptual boundaries between phonemes of the native language, momentarily weakening discrimination abilities. Furthermore, between age 7 and 9, phonological awareness develops substantially, along with reading skills. As suggested by Burnham (2002) [1] and Horlyck et al., (2012) [20], the development of reading skills imposes greater cognitive demand on children and affects their ability to discriminate between phonemes. It is also known that children do not weigh the visual cues provided by the speaker's face as much as adults do. For example, in a study of audiovisual perception in 5- to 14-year-old children and adolescents, Ross et al. (2011) [36] showed that the audiovisual gain in intelligibility steadily increased in this age group. Integrating this new sensory modality (auditory and visual) to a greater extent during childhood and adolescence might increase the cognitive load and influence auditory discrimination. Although these results cannot explain the change in vowel-pair discrimination scores in the current study, it is possible that this improved skill interacts with reading skills and other perceptual abilities that evolve before age 10. These hypotheses need to be explored in further studies involving, for instance, larger sample size. Such results could have impact on auditory assessment in typically-developing children. Indeed, changes in auditory vowel perception (at least for the two vowels contrast under study) characterize typical language development up to 10 years old.

It should be noted, however, that the stimuli tested in the current experiment consist in a limited set of synthesized vowels presented in isolation. Although the VLAM model has been shown to generate very realistic stimuli allowing fine control of acoustic parameters, further experiments with natural speech in a more realistic context are needed to confirm the aforementioned hypothesis on the development of speech perception. Another factor to further explore is the influence of language exposure on discrimination abilities. Despite the fact that children were native speakers of Quebec French and used Quebec French at home, they had little exposure to English at school (one hour per week). Their knowledge of English might slightly vary between speakers and, thus, could influence the results. Also, despite our efforts to include, in our participant sample, children who had Quebec French as their sole language at home, it is possible that children were also exposed to another language, besides French and English. Further studies should measure the degree of exposure to other languages to control for the effects of such variables on the discrimination scores.

5 Conclusion

The current paper aimed at investigating the development of auditory discrimination abilities for vowels in school-aged francophone children and adults. Results show that although children have attuned to their first language's category boundaries, their auditory discrimination skills still mature between 6 and 10 years old.

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