Perceptual Development of the Duration Cue in Dutch /a-a/

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Abstract
The use of duration as a perceptual cue in Dutch /a-a/ is studied in children aged 5 and 7, and adults. Usually, Dutch listeners use both vowel duration and spectral composition as perceptual cues for /a/ and /a/, but they can use duration alone. Despite the vowel contrast’s salience, five-year-olds do not yet use duration as adults: half of them did not use duration at all. The seven-year-olds did not differ from the adults, implying that the use of duration as a single cue is acquired before age 7, but mostly after age 5.

1. Introduction
The Dutch language has vowels that are intrinsically either short or long [1]. The intrinsic duration of long vowels is about twice as long as that of short ones. Examples of short-long pairs are /a-a/ as in man-maan (= ‘man’-’moon’) and /a-a/ as in bot-boot (= ‘bone’-’ship’). The acoustic difference between a short and a long vowel is not restricted to duration, but is also cued by their spectral composition. Usually, listeners use both cues to identify a vowel as either /a/ but is also cued by their spectral composition. Usually, between a short and a long vowel is not restricted to duration, R« $D«$ Listeners perceived /a/ however, showed that both /a/ and /a/ were perceived when only the duration of [a] was varied in a CVC word [4]. Listeners perceived /a/ in case of short [a]-vowels and /a/ in case of long [a]-vowels. This pattern of results was also found with isolated vowels [2]. Apparently, even though the Dutch usually base their perception of these vowels on both spectral and durational cues, they can, under certain circumstances, make the distinction on the basis of duration alone.

In the present research we were interested in the perceptual development of the duration cue in the Dutch vowels /a/ and /a/. Usually, children learn to classify native phoneme contrasts more sharply with age. Initially, they may weight certain acoustic cues in the speech sounds differently from adults, but their perception becomes more adult-like with age, e.g. [5]. For some phoneme contrasts the process of fine-tuning native categories may last until the children’s early teens [6]. Vowels, however, are thought to be learned early.

The development of the weighting of spectral and durational cues in the Dutch vowel contrast /a-a/ has been studied before [7]. The perception of children aged 4, 6 and 9 was compared with adult perception. The vowels’ formant frequencies were varied along a continuum in 7 spectral steps, but duration had a binary distribution: either consistent with /a/ (= short) or with /a/ (= long). Children of 4 and 6 years old weighted formant information less heavily than the older children and adults. With respect to duration the young children did not differ from the adults. It could, however, not be concluded that children classified the entire duration dimension of this contrast as adults did, due to the binary distribution of that cue.

The goal of the present study was to determine how children aged 5 to 7 use the entire duration dimension in the perception of Dutch /a-a/ in comparison with adults. Earlier findings predict that children will be able to use the duration dimension in an adult-like manner.

2. Experiment I
The present experiment examined the developmental differences in classification of an /a-a/ continuum by 5- and seven-year-old children and adults. Only duration was varied along a stimulus continuum, whereas formant frequencies were kept constant, as was done in earlier studies [2, 4].

2.1. Method
2.1.1. Participants
There were 62 participants: 20 adults (17 female), 20 seven-year-olds (9 girls) and 22 five-year-olds (9 girls). All were native speakers of Dutch. The children were recruited at two primary schools in the south of the Netherlands. The adult group consisted of the children’s parents and teachers. The children who participated (i) performed normally in school, (ii) had no history of ear infections, (iii) had no respiratory infections during testing, and (iv) did not wear ear tubes.

2.1.2. Materials
The word pair man – maan (= ‘man’ - ‘moon’) spoken by a phonetically trained, male speaker of Dutch was recorded on DAT tape in a sound-treated booth. Dutch children are familiar with these words, which can easily be represented by pictures. An Audio-technica AT841a microphone was used. The signal was high-pass filtered at 75 Hz. The recordings were transferred onto a Unix computer and downsampling from 48 kHz to 32 kHz with an amplitude resolution of 16 bits. The speaker pronounced three words in isolation: (i) man, /man/ (F1= 566 Hz, F2= 922 Hz ), (ii) maan, /maan/ (F1= 727 Hz, F2= 1377 Hz ), and (iii) another maan with a vowel that had formant frequencies intermediate between /a/ and /a/, which we will call [a’] henceforward. The formant values of [a’] (F1= 640 Hz, F2= 1152 Hz), lie very close to the means of the formants from [a] and [a’], i.e. 647 Hz and 1150 Hz. The first two formants of [a] and [a’] fall within the range of formant frequencies reported for these Dutch vowels, e.g. [8].

The intermediate vowel was used as a basis for making a 7-step duration continuum. The long /a/, with a duration of 308 ms, was shortened in steps of four periods of the speaker’s fundamental frequency, approximately 30 ms, to the short /a/ with a duration of 129 ms. The speaker’s intonation was flat with a mean F0 of 127 Hz.
2.1.3. Procedure

All experiments were run in a quiet room at the children’s schools. A Toshiba Satellite 1400 153E laptop computer was used to present stimuli and to register responses. Stimuli were presented over Beyerdynamic DT 770 headphones at a comfortable listening level.

Child procedure: The children completed the Auditory Discrimination Test (ADIT) [9] followed by classification of the /a/-/æ/- continuuim. In the ADIT test, children had to give at least 14 correct answers out of 15 to be admitted further testing. In front of the child lay two pictures representing a minimal pair of words. The child was asked to point at the picture showing the word presented over headphones and to say the word aloud. Apart from a check for the child’s normal language development, ADIT served as practice with the response method for the rest of the experiment.

If children had passed the ADIT test, classification of the /a/-/æ/- continuum was administered. The test started with a live-voice introduction of the two words. The pictures representing the categories were introduced, and the child and the experimenter took turns playing the game. Next, the endpoint stimuli were introduced over headphones: one picture was placed in front of the child and the corresponding sound file was played four times while the child practiced answering by both saying the word and pointing at the picture. Then the other picture was placed in front of the child, and the procedure was repeated. After that, both pictures were placed in front of the child and the endpoints were presented one after another, two times each. Practice started after the experimenter had told the child that the words had got mixed up and that the child had to indicate after each word to which picture that word corresponded. The first session of practice trials, in which each endpoint was presented four times, was used to get the child acquainted with the procedure, and during the second set of practice trials, the child had to give 7 correct answers out of 8 for his/her data to be included in the analyses.

Each stimulus from the continuum was repeated 6 times, resulting in 7 stimuli x 6 repetitions = 42 trials. There was one break halfway, in which children completed a part of a puzzle. After the break both endpoint stimuli were each presented twice to check whether the child had remembered them correctly. The session lasted 20-25 minutes. The children received stamps on colored paper card for answering by both saying the word and pointing at the picture. Then the other picture was placed in front of the child, and the procedure was repeated. After that, both pictures were placed in front of the child and the endpoints were presented one after another, two times each. Practice started after the experimenter had told the child that the words had got mixed up and that the child had to indicate after each word to which picture that word corresponded. The first session of practice trials, in which each endpoint was presented four times, was used to get the child acquainted with the procedure, and during the second set of practice trials, the child had to give 7 correct answers out of 8 for his/her data to be included in the analyses.


2.2. Analysis and results

All children completed the ADIT test successfully. The /a/-/æ/- test criterion of 7 correct answers out of 8 was passed by 12 of the 22 five-year-old children, 19 seven-year-olds and all adults. Remarkably, almost half of the five-year-old children did not pass the criterion for participating in this classification test. These children’s responses to the introduction data revealed that they perceived the vowel in the shortest [ma’n], correctly as that in man (/man/), but that they consistently perceived the longest version of [a'], which was intended as an /æ/, as the vowel in man as well. The remaining five-year-olds’ mean age was 5;1 (range: 4;2 to 5;5), the seven-year-olds had a mean age of 6;11 (range: 6;5 to 7;6). The adult mean age was 33 varying from 19 to 48.

From each classification function, the phoneme boundary, i.e. the point of crossover between the categories, and the boundary width, i.e. the crossover region, were determined. The listeners’ classification results were represented as percentages of /a/ responses per stimulus. These were transformed to z-scores to be submitted to a Linear Regression analysis per listener, with z-score as dependent variable and stimulus duration as independent variable. If a listener’s z-scores could not be fitted by a linear function, that listener’s data were not further analyzed. Data from 20 adults, 8 5- and 17 seven-year-olds remained. The phoneme boundary was fixed at z = 0, the 50% point. Boundary widths were defined as the 25%-75% range of /a/ responses (from z = -0.674 to z = 0.674).

Vowel duration (ms)

Figure 1: Classification functions for each of the age groups: five-year-olds, seven-year-olds and adults.

The classification functions for the /a/-/æ/- continuum by each of the three age groups are shown in Figure 1. A two-way ANOVA with factors Age Group (3) and Duration (129-308 ms) on the listeners’ proportions of /a/ responses was run. No overall effect of Age Group was found. But a main effect of Duration and an Age Group × Duration interaction were present [F(6,294) = 232.6, p < .001; F(12,294) = 2.2, p = .014]. Post-hoc tests did not reveal further age differences.

The phoneme boundaries and boundary widths are given in Table 1. The effect of Age Group on each measure was examined in a one-way ANOVA with between-subjects factor Age Group (3). There was no effect of Age Group on the location of the phoneme boundary. All participants put the boundary between /a/ and /æ/ at approximately the same location. But boundary width was affected by the listener’s age [F(2,42) = 6.6, p = .003]. Tukey HSD post-hoc tests showed that the five-year-olds’ boundary width was larger than that of the adults and the seven-year-olds. The interval
over which perception changed from /ɑ/ and /æ/ decreased with age.

Table 1: Phoneme boundaries and boundary widths by age group.

<table>
<thead>
<tr>
<th>Age group</th>
<th>Phoneme boundary</th>
<th>Boundary width</th>
</tr>
</thead>
<tbody>
<tr>
<td>five-year-olds</td>
<td>200 ms</td>
<td>38.5 ms</td>
</tr>
<tr>
<td>seven-year-olds</td>
<td>207 ms</td>
<td>30.5 ms</td>
</tr>
<tr>
<td>adults</td>
<td>208 ms</td>
<td>27.9 ms</td>
</tr>
</tbody>
</table>

2.3. Discussion

The goal of this experiment was to study how children aged 5 and 7 use the duration cue to distinguish between the Dutch vowels /ɑ/ and /æ/ as adults do. Adult responses replicated earlier findings by showing that Dutch listeners can differentiate between /ɑ/ and /æ/ on the basis of duration alone [2, 4]. The seven-year-olds treated duration similarly to adults. This shows that these seven-year-olds had already mastered this contrast quite well. The other half of the five-year-old children did not meet the criterion: they responded hearing only /mɑn/, and not /maan/.

What may have caused this difference in vowel perception within the group of five-year-olds? The children who did meet the criterion perceived the contrast almost adult-like. The children who did not meet the criterion did not seem to use duration at all. It could not be the case that the children only responded the word they were familiar with, since it had been checked that the children knew both /mɑn/ and /maan/ during the task introduction. Apparently, these five-year-olds did not use the duration dimension in distinguishing between /ɑ/ and /æ/, not even after a short training with the testing materials, which varied only in duration. As a result, their responses were based on the aspect of the signal that did not change between stimuli: the vowel’s spectral composition. These five-year-olds perceived [a’] consistently as an /ɑ/, which implies that the intermediate vowel was not ambiguous, at least not to these listeners. These findings suggest that young Dutch listeners do not yet use duration in vowel perception as adults do. This explanation is supported by production studies. Dutch children of 4 years of age produce the length distinction between /ɑ/ and /æ/ less clearly than adults do [10]. In addition, Dutch children produce the durational contrast between short and long vowels more distinctly with age [11].

Summarizing, this experiment showed that seven-year-old children and adults, and some five-year-olds distinguished /ɑ/ from /æ/ based on duration alone. Interestingly, half of the five-year-olds did not seem to use duration as a cue for vowels. This ‘split’ within the group of five-year-olds suggests that the use of the duration cue in perceiving /ɑ/ and /æ/ is learned around age 5. This possibility was addressed in experiment II.

3. Experiment II

In experiment I, the development of duration perception in an /ɑ-æ/ continuum based on duration alone revealed that almost half of the five-year-old children did not pass the testing criterion, suggesting that these children could not use duration as a single cue in the perception of /ɑ-æ/. In the present experiment, the same five-year-old children were tested on their perception of the same continuum 9 months after the first test, to address the following questions. With more language experience, (i) do more five-year-olds use duration as an acoustic cue to differentiate between /ɑ/ and /æ/? (ii) does the perception of the children who already used duration become more adult-like? With respect to the latter question, the children are expected to show smaller boundary widths in comparison with the earlier test. Furthermore, if the use of duration as a cue in vowel perception is learned around age 5, it is expected that more five-year-old children will reach criterion in the present experiment than in experiment I.

3.1. Method

Experiment II was administered 9 months after experiment I. The testing procedure was similar to that of the earlier experiment. The ADIT test was reduced to form an introduction to the task and response manner. The /ɑ-æ/ continuum was tested as earlier and the same five-year-olds participated.

3.2. Analysis and results

Fifteen of the 22 five-year-old children passed the criterion of 7 correct answers out of 8 during practice. Their mean age was 5;10 (range: 4;11 to 6;3). One child who had met criterion in experiment I did not succeed in doing this now. On the other hand, 4 children who had not passed the criterion earlier did meet it this time. The other children, who again did not reach criterion, responded in the same way as they had done earlier: they perceived only /ɑ/. The data were analyzed as in experiment I, which resulted in usable data from 13 five-year-olds: 10 children who had already used duration in experiment I, and 3 children who used duration for the first time.

3.2.1. Children who had used duration in experiment I

The mean phoneme boundary for the five-year-old children who had used the duration cue before now lay at 211 ms. This was very close to the adult boundary of 208 ms. Paired samples t-tests on these children’s phoneme boundaries from experiments I and II showed that the boundary locations did not differ as a function of testing moment.

The mean boundary width for these five-year-olds was 36.6 ms. Paired samples t-tests on the children’s boundary widths showed no differences between the two experiments. A one-way ANOVA with between-subjects factor Age (3) showed that the five-year-olds whose boundary widths had differed from those of both seven-year-olds and adults in experiment I, now only significantly differed from the adults.
3.2.2. Children who had not used duration in experiment I

The mean phoneme boundary of the five-year-olds who had not used duration earlier lay at 230 ms with a boundary width of 38.7 ms. Compared to adult perception, they accepted longer versions of /a:/ still as /a/. And, they were less consistent than the adults. On average, these children identified the 4 longest stimuli as /a/ in 76% of the cases, whereas the five-year-olds who had used duration before had an average of 85% /a/ responses to those stimuli. Thus, the five-year-olds who used duration in perceiving /a/ and /a:/ for the first time were less inclined to identify the longer stimuli as /a:/.

3.3. Discussion

This experiment was set up to further investigate how the use of duration as a single cue in vowel perception develops at age 5. Our results confirmed both expectations. Firstly, more five-year-old children reached criterion in experiment II than in experiment I, which means that more of them had learned to use duration as a cue in vowel perception. And secondly, after more language experience, the five-year-olds became more consistent in their classification behavior as shown by smaller boundary widths. But still one out of every four children tested did not use duration to distinguish /a/ from /a:/.

Contrary to expectation, not all children of almost 6 years of age use duration as a single cue in a salient vowel contrast as /a-/a/-. In everyday Dutch, both duration and spectral composition differ between /a/ and /a:/-. Children aged 4 already use spectral information to identify /a/ and /a/-. [7], whereas older children in the present study did not attend to duration. Possibly, the vowels’ spectra form a more reliable or more informative cue in perception, and are therefore attended to earlier. This explanation finds support in the finding that durational differences between short and long vowels are not present in all Dutch syllables, but only in stressed ones [12], and secondly, by the fact that adults have been found to weight spectral information more heavily than duration [3]. In sum, we suggest that use of the duration dimension in Dutch vowel perception may develop late due to the relatively low information content of that cue.

4. Conclusion

This paper addressed the perceptual development of the use of duration as a single cue for perceiving Dutch /a/ and /a:/ in children aged 5 and 7, and adults. Experiment I showed that seven-year-old children treated durational information in the same way as adults did, and further that half of the five-year-olds performed similarly, apart form being less consistent. Experiment II showed that more five-year-olds had learned to use duration as a cue in vowel perception with more language experience, but also that still one out of every four five-year-old children did not use the duration cue to distinguish between /a/ and /a:/.

5. References


