Table 2. Mean MMR amplitudes (in μV) for the adults in the current study and the infants in [4].

Age Group	Distribution Type	Standard Vowel	N	Mean	SD	Confidence Interval	
						Lower limit	Higher limit
Adult	**Unimodal**	**[ɛ]**	10	−1.12	0.99	−1.82	−0.41
		[æ]	9	−1.05	1.65	−2.31	+0.22
	Bimodal	**[ɛ]**	11	−0.35	0.86	−0.93	+0.23
		[æ]	9	−1.21	1.32	−2.23	−0.19
Infant	**Unimodal**	**[ɛ]**	6	−0.59	0.86	−1.71	+0.52
		[æ]	5	+1.21	1.23	−0.71	+3.14
	Bimodal	**[ɛ]**	5	+2.26	0.83	+0.97	+3.55
		[æ]	6	+0.48	0.80	−0.55	+1.50

With within-group standard deviations (SD) and 95% confidence intervals, calculated per Distribution Type and Standard Vowel.[a]

[a] For the infants the alpha level for the confidence intervals is 2.5% instead of 5%, because the infant study included an additional group of sleeping infants. For details see [4].

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3. Smaller effectiveness of distributional training in adults than in infants

From the statistical significance of the distributional effect in infants [4] and the statistical non-significance of the effect in adults (the present paper) we cannot yet conclude that the effect is greater in infants than in adults. A valid test requires a direct comparison of the two age groups. The difference in MMR amplitude between the Bimodal and Unimodal groups (i.e., Bimodal MMR – Unimodal MMR) for the adults was +0.30 μV (= −0.78 μV–−1.08 μV; i.e., in the unexpected direction, though non-significant), whereas that for the infants [4] was +1.06 μV (= +1.37 μV–+0.31 μV). This age difference does not appear to be due to adults having a smaller MMR amplitude in general than infants, because the literature review in the Method section (section 7) suggested that this amplitude is probably *greater* in adults than in infants. The age difference could therefore be due to a truly smaller effect of distributional training in adults than in infants. To verify this, the current section presents a numerical comparison of the infant and adult MMR amplitudes. As determined by the literature review in the Method section (section 7), the comparison requires a normalization of the MMR amplitudes, which should include a correction for the opposite polarity of adult and infant MMRs and a scaling of the size of the MMR. To implement the normalization (or something equivalent to normalization), we multiplied each adult's MMR amplitude by −1 to correct for the negative polarity, and we multiplied each infant's MMR amplitude by a scaling factor to correct for the smaller size. Before applying the scaling factors estimated from the literature, which were 1.18 and 1.41 (Method section 7), we present the results for a more conservative scaling factor of 1.00 (i.e. no scaling), which is smaller than the estimates; this scaling turns the mean MMR for adults into −0.30 μV, and that for the infants into +1.06 μV, giving a difference of 1.36 μV.

Scaling factor of 1. Using a conservative scaling factor of 1, we performed an ANOVA with the normalized MMR amplitude as the dependent variable, and Age Group (infant vs. adult), Distribution Type (unimodal vs. bimodal) and Standard Vowel ([æ] vs. [ɛ]) as between-subject factors (given that in [4] a strong interaction was observed between Distribution Type and Standard Vowel, Standard Vowel was included to be able to extract possible interactions with this variable). The ANOVA yielded the following normalized MMR amplitudes per Age Group and Distribution Type (as visible in Figure 4): infant unimodal 0.31 μV (CI = −0.38~+1.00 μV), infant bimodal 1.37 μV (CI = +0.68~+2.05 μV), adult unimodal 1.08 μV (CI = +0.56~+1.60 μV) and adult bimodal 0.78 μV (CI = +0.27~+1.29 μV).

Crucially, the interaction between Age Group and Distribution Type was significant ($F[1,53] = 5.05$, $p = 0.029$). Thus, the effect of distributional training differed between infants and adults (see below). Further, the interaction between Distribution Type and Standard Vowel was significant ($F[1,53] = 4.85$, $p = 0.032$), as well as the triple interaction between Age Group, Distribution Type and Standard Vowel ($F[1,53] = 13.99$, $p = 0.0005$). The other interaction effect (between Age Group and Standard Vowel) and the main effects were not significant (all p-values >0.21).

As the number of participants was not the same in all groups, it is relevant to note that the crucial interaction between Age Group and Distribution Type did not depend much on the way the terms for the ANOVA were entered in the linear model. With "Type-III sums of squares", the p-value for each main or interaction effect is calculated from a comparison between the full model (i.e. the model with all main and interaction terms) and the full model from which only this one term was dropped. This led to the above-mentioned p-value of 0.029 for the interaction between Age

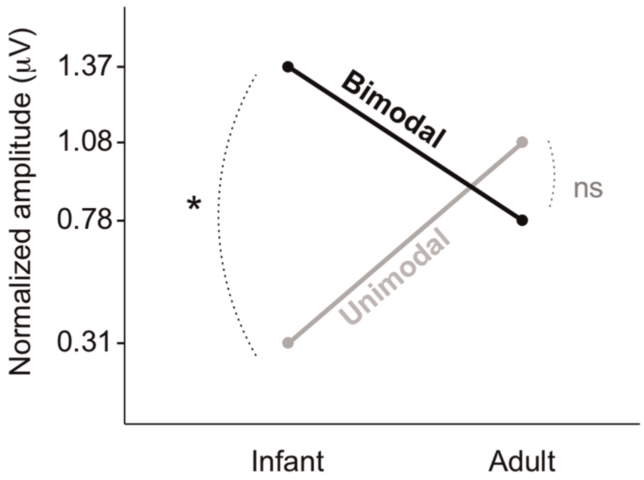

Figure 4. The interaction between Age Group and Distribution Type. Age group: infant, left vs. adult, right. Distribution Type: unimodal, grey vs. bimodal, black.
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Group and Distribution Type. With "Type-I sums of squares", the terms are entered into the linear model one by one and the *p*-value for each term depends on when the term is added. Under the constraint that the three two-way interaction terms are added after the three main terms and before the three-way interaction term, the *p*-value for the interaction between Age Group and Distribution Type depended only slightly on the order in which the two-way interactions entered into the model: it was 0.027 if this term was entered first, 0.024 if it was entered after Distribution Type × Standard Vowel but before Standard Vowel × Age Group; 0.025 if it was entered after Standard Vowel × Age Group but before Distribution Type × Standard Vowel; and 0.023 if it was entered last. By contrast, the interaction between Distribution Type and Standard Vowel was not robust to such variation. With Type-III sums of squares, the *p*-value of the interaction was as shown above (i.e., $p = 0.032$), while with Type-I sums of squares the effect was non-significant, irrespective of the chosen order of factors (i.e., the *p*-value ranged from 0.23 to 0.27). This difference in significance is due to the strong effect of the three-way interaction term: only if this triple term is present and has taken away much of the variance does the interaction between Distribution Type and Standard Vowel provide a significant improvement to the model. The robustness of the interaction of Age Group and Distribution Type, together with the lack of robustness of the interaction of Distribution Type and Standard Vowel, means that the former effect has been shown more credibly than the latter.

The observed interaction between Age Group and Distribution Type is pictured in Figure 4. The figure suggests that the difference in the normalized MMR amplitude between unimodally and bimodally trained participants was larger (i.e., more positive after normalization) for the infants than for the adults. When controlling for a possible effect of Standard Vowel, this difference is significant for the infants (mean difference normalized bimodal – unimodal = +1.06 μV, 95% CI = +0.09∼+2.03 μV), thus indicating an effect of distributional training, and not significant for the adults (mean difference normalized bimodal – unimodal = −0.30 μV, 95% CI = −1.03∼+0.43 μV). In view of the significance of the interaction between Age Group and Distribution Type, it is now possible to interpret the significant effect of distributional training for the infants as indeed being larger (i.e., +1.06–−0.30 μV = +1.36 μV, 95% CI = +0.15∼+2.57 μV) than the non-significant effect for the adults (if that effect exists at all).

Other scaling factors. The statistical significance of the result depended on the size of the scaling factor by which the infant MMR amplitude was multiplied. With the conservative value of 1.00 used above, the *p*-value for the interaction between Age Group and Distribution Type was 0.029 (Type-III sums of squares). With the scaling factors estimated above (Method section 7), namely 1.18 and 1.41, which express the idea that adult MMRs are bigger than infant MMRs, the *p*-value would be lowered to 0.018 and 0.010, respectively. With a scaling factor of 0.8172, which expresses the opposite assumption from that derived from the literature, namely that infants have a somewhat *larger* MMR amplitude than adults, the *p*-value would become exactly 0.05. We can conclude that for a large range of plausible scaling factors, the effect of distributional training is reliably smaller for adults than for infants.

Discussion

The current study provides the first evidence in a direct comparison that distributional training of speech sounds is less effective in adulthood, when new languages must be mastered, than in the first months of life, when infants start acquiring native speech sounds. Specifically, an earlier study [4] showed that Dutch 2-to-3-month-old infants who are exposed to a bimodal distribution encompassing the Southern British English vowel contrast /æ/∼/ε/, have a larger MMR amplitude, and thus supposedly discriminate the two test vowels [æ] and [ε] better, than infants exposed to a unimodal distribution. The current study demonstrates that this bimodal advantage is smaller (if at all present) in Dutch adults than in Dutch infants.

The presence of a bimodal advantage in Dutch adults is uncertain, because the difference in test vowel perception between bimodally and unimodally trained adults was not significant. It may be hypothesized that this non-significance was due to a ceiling effect (i.e., top discrimination) in both groups. After all, in the Netherlands English is a compulsory subject of study in middle school and high school, and it is also a language that can be listened to easily on television and other media. However, such a ceiling effect is unlikely. The MMR amplitudes in both groups were rather small (with 95% confidence intervals close to zero), suggesting relatively poor discrimination (cf., the amplitudes in adults listed in Table 1). Moreover, it has been shown that *despite* their experience with English, Dutch adults have trouble distinguishing the English vowels that were used in the current study [6–9]. Similar results have also been obtained with other languages: for instance, adult native speakers of Spanish have considerable trouble in discriminating tokens of Dutch /ɑ/- and /a/, irrespective of the length of exposure to the Dutch language [56].

Notwithstanding our efforts to make a sound comparison of the effect of distributional training in infants and adults, it is clear that future research is needed to replicate our results and to confirm the feasibility of our approach. For confirming this feasibility, it will be particularly important to ascertain that infant MMRs truly reflect behavioral discrimination just as adult MMRs do (section 1 below). Relatedly, future research should aim to get a much more detailed understanding of the neural processes underlying infant and adult MMRs, so that differences between them can be explained better (section 2 below presents a tentative rough explanation for the current results).