Individual Differences in Phonological Proficiency and Correlation with Pitch Sensitivity: Three Types of Perceivers

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Native listeners' phonological proficiency has traditionally been analysed as a uniform trait in a healthy population, but there is a growing interest in the estimation of individual differences in phonological processing [1, 2]. Neurophysiological responses recorded during perception of native phonemic contrasts have so far been interpreted to indicate two types of listeners – gradient vs. discrete perceivers, where gradient perceivers rely more strongly on acoustic information felicitously delivered to the cortex, while discrete perceivers incorporate top-down category representation information at that cortical level [3]. However, recent findings in neuroanatomy motivate a hypothesis that the neural basis of phonological proficiency can include *several* processing mechanisms. Each of these mechanisms is a potential source for individual variation: For example, differences in cortical thickness and surface area in language-related brain structures have been associated with not only the natural variance in listeners' phonological proficiency when using word accent tones to interpret morphology [2, 4] but also with the listeners' extra-linguistic skills, such as pitch discrimination ability [5].

To investigate whether generic psychoacoustic abilities play a role in the different perception styles in phoneme context, we tested native Swedish listeners' pitch discrimination and vowel categorisation and discrimination ability. The aim was to gauge the heterogeneity of phonological proficiency and measure it in three aspects: i) *phonemic aptitude*, defined as how categorically the individual listeners perceive inter-category vowel sounds in a linguistic context, ii) *phonetic aptitude*, as in how accurately they judge differences between those inter-category vowel sounds as a function of acoustic distance, and iii) *acoustic aptitude*, measured as their pitch discrimination ability. We then assessed the relation between the performance at the different levels. Our study consisted of three experiments (Table 1).

Sixty native Swedish speakers (age: 19-40, mean: 27.13 years, 42 males) without any known hearing difficulties, language deficits, or neuropsychiatric diagnoses completed the experiments. All participants were recruited via the online service Prolific and were paid for their participation.

Single-subject analysis was done in base R. One outcome measure per participant was obtained from each experiment. Phonemic aptitude performance scores ranged from 5.2 to 187.6 ($M = 64.8$, $SD = 52.2$), phonetic – from 0.03 to 1.5 ($M = 0.88$, $SD = 0.38$), acoustic – from 1.4 Hz to 20.8 Hz ($M = 5.86$, $SD = 4.11$), indicating individual differences among the perceivers on all three performance levels. Group level analysis compared measurement outcomes from the phonemic, phonetic, and acoustic experiments. Since all three variables are random and contain error, the *lmodel2* library in R was used to fit model II ranged major axis (RMA) regression to compare the performance between the three levels. Phonemic aptitude was not predicted by phonetic aptitude ($R^2 = 0.03$, $P_{perm} = 0.11$), suggesting that these two aptitudes are separable aspects of phonological proficiency. Acoustic aptitude did not predict phonemic aptitude ($R^2 = 0.01$, $P_{perm} = 0.19$) but it did predict phonetic aptitude ($R^2 = 0.12$, $P_{perm} = 0.01$), showing that low-level frequency sensitivity may be involved in phonetic judgements.

To inspect the heterogeneity of phonological proficiency, a k-means cluster analysis was conducted using *cluster* and *factoextra* libraries in R. Based on their scaled phonemic and phonetic aptitude scores, the perceivers were grouped into clusters with maximum similarity within and maximum dissimilarity between them. Following the "elbow point" method, the best number of clusters was determined to be three, which explained 69% of the total variance. Clustering results showed the following types of perceivers (Figure 1): those that performed a) above average in both phonemic and phonetic aptitude tests, b) below average in both tests, and c) above average in the phonetic aptitude test but below average in the phonemic aptitude test. Thus, phonological proficiency appears to be more complex than a 1-dimensional axis between gradient and discrete perceivers. Interestingly, no participants exhibited the pattern opposite to c), which suggests that superior phonetic aptitude is a prerequisite for, or a side-effect of, developing and/or maintaining superior phonemic aptitude.

Table 1. Setup of the three experiments that measure phonemic, phonetic, and acoustic aptitude.

	Phonemic aptitude	**Phonetic aptitude**	**Acoustic aptitude**
Task	2-alternative forced choice, categorisation	2-alternative forced choice, discrimination	Transformed 1 up/2 down staircase [6]
Stimuli	Minimal CVC word pairs; V replaced with synthetic inter-category vowels	Synthetic inter-category vowels; acoustic distance $(\Delta F1+\Delta F2)/2$ varied from 0 to 0.375 Bark	Pure sine tones
Scope	6 inter-category continua (*kok—kåk*, *tår—tar*, *tar—tär*, *häl—hel*, *fyr—fur*, *tur—tör*)	6 inter-category continua (/uː/—/oː/, /oː/—/ɑː/, /ɑː/—/ɛː/, /ɛː/—/eː/, /yː/—/ʉː/, /ʉː/—/øː/)	1/240th to 2 semitones (519-582 Hz, in steps of 0.25 Hz)
Trials	237 (3 blocks of 79)	432 (3 blocks of 144)	4 (2 runs in 2 directions)
Outcome measure	Slope of logistic regression (vowel ~ likelihood of choice), average of all 6 continua	Slope of linear regression (acoustic distance ~ % correct), average of all 6 continua	Average Just-Noticeable-Difference threshold (JND) at 70 % correct, Hz

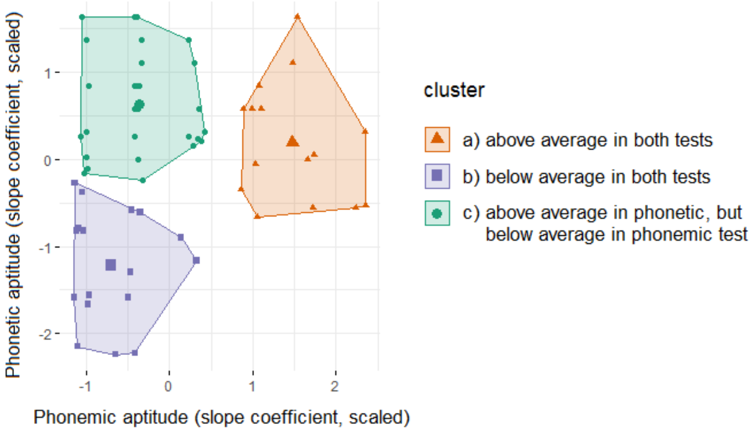

Fig.1 Results of clustering analysis. Perceivers were grouped by phonemic and phonetic aptitude scores.

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