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Heredity and Environment in Phoneme Articulation: Hereditary and Environmental Contributions to Articulation Proficiency

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Abstract. Large twin samples and recent applications of multiple regression techniques to behavioral genetics methodology makes possible evaluation of genetic and environmental contributions to the articulation proficiency of individual phonemes. Factor analysis of the articulation scores from 256 MZ and DZ twins and 124 of their non-twin siblings (all children ranged from 2; 11 to 9; 8 years) were conducted to reduce a 50-item articulation test to a more manageable set of five articulation factors. The twins' factor scores were then analyzed using multiple regression procedures to determine the extent to which the individual factors resulted from genetic and/or environmental influences. The /r/ and /ʃ, tʃ, dʒ/ factors were found to have strong genetic components, while the /l, j, w/ factor was found to be strongly influenced by environmental sources of variation.

Key words: Articulation proficiency, Speech, Twins

INTRODUCTION

Inborn and environmental contributions to articulation proficiency at the phonemic level

Researchers have been interested in the genetic and environmental contributions to articulation proficiency for at least two decades [4-9]. This interest may be motivated by both theoretical and practical considerations. From a theoretical standpoint, the genetic and environmental contributions to articulation proficiency might profitably contribute to the understanding of phonological acquisition more generally. From a practical standpoint, there are implications for the field of speech intervention. For example, if mechanisms underlying production of a given phoneme are due primarily to genetic factors, then environmental intervention in the form of speech training to correct misarticulation may not be particularly helpful. In contrast, various other phonemes may have less heritable influences and be more susceptible to intervention.

Unfortunately, the extant literature has only examined genetic contributions to global articulation, without considering potential differences in heritability as a function of phoneme type. Among the first of these investigations were those by two authors [7, 8] in which the articulatory performance of 101 same-sex twin pairs on the Templin-Darley Screening Test of Articulation [13] was examined. Their sample consisted of 64 monozygotic (MZ) and 37 dizygotic (DZ) twin pairs, ranging from 3 to 8 years of age. After partialling out the confounding influence of socioeconomic status (SES), the authors observed intraclass correlations of .85 and .58 for MZ and DZ boys, respectively; and r's of .90 and .54 for MZ and DZ girls, respectively. The drop in intraclass correlations from MZ to DZ twin pairs for both genders suggests that the MZ twin pairs, who share genetic and environmental endowment, are more alike in articulatory proficiency than DZ twin pairs, who share the environmental but only half the genetic endowment [11]. On the basis of these results, the authors concluded that a significant portion of the phenotypic variation in articulation proficiency was attributable to genetic factors.

A more recent study has failed to confirm this finding. Using the same version of the Templin-Darley Screening Test, its authors examined the articulatory performance of 79 twin pairs (50 MZ and 29 DZ) ranging from 3 to 6 years of age [9]. Unlike the previously described study [8], the authors of this more recent study found no difference in intraclass correlations for MZ and DZ twins (r's = .96, and .92 respectively), suggesting little genetic influence. This discrepancy in findings is troubling. One possible explanation for the inconsistency might be the differences in reporting protocol. One aspect of the more recent study not described above was that it initially revealed *differential heritability* for boys and girls [9]. Articulation proficiency appeared to be heritable for boys, but not for girls. Further analyses revealed heritability in both genders, but only after removing the variance due to SES. The authors noted that "the relation between socioeconomic status and articulation obscured the demonstration of the hereditary influence upon the females' articulation scores" (p. 444). So, SES interacted with gender.

In contrast, the same study [9] did not report separate MZ and DZ intraclass correlations as a function of gender, nor did it consider the potential mediating influence of SES. Because of the differences in reporting protocol, direct comparison between this study and the two earlier ones [7, 8] is not possible. Because its sample of DZ twins included a majority of girls (specifically, 36 out of the 58 DZ twins), and SES was not statistically controlled, the results of the more recent study [9] may have been confounded in a vein similar to the initial analysis of the authors of the earlier studies [7, 8]. Thus, if demonstrating heritability for girls is obscured by failing to partial out SES, then the failure of the authors of this study to observe heritability overall could be due to the high proportion of girls in their sample.

Interestingly, at the end of the 1980s two authors [6] reexamined the heritability question using a subset of the original data of the forementioned study [9]. They noted of the earlier study, "since both groups' intraclass correlations on the articulation test were very high ... it made sense to ask whether there were greater *qualitative* similarities of articulation among MZ twins''. The qualitative similarities consisted of shared errors (including substitutions, omissions and distortions) on individual Templin-Darley items. It was found that among MZ twins, 82 % of the total errors were shared errors, while for DZ twins only 56 % were shared. This difference was statistically significant. However, specific *classes* of shared errors were not necessarily more likely to occur among MZ than DZ twins. That is, if a child made an omission error, then an MZ cotwin was no more likely than a DZ cotwin to make an omission error. This finding suggests that heritable influences are at work in general in accounting for variation in children's misarticulations, but it does not seem to be involved in accounting for specific types of errors.

Most recently, a study examined the concordance rates of 32 MZ and 25 DZ twin pairs on a number of speech- and language-relevant developmental disorders [5]. The children ranged in age from 6 to 12 years of age, with males making up the majority (i.e., 75 %). Concordance rates for reported treatment of articulation disorders were .95 and .22 for MZ and DZ twins, respectively. Thus, strong genetic influences would seem to be at work. However, an equally plausible interpretation is that parents of probands were more likely to seek intervention of the cotwin when twin pairs were monozygotic, regardless of the actual need for intervention. That is to say, parental knowledge of zygosity status may be the primary reason behind both twins receiving intervention.

Modelling heritability using multiple regression

A general limitation of this research has been that it examined only *global* articulation proficiency. But of course, not all phonemes are produced with the same anatomical components and perceptuomotor skills. Production varies in terms of manner and place of articulation, and phonemes vary with respect to their entry in the child's repertoir. With such interphonemic variation in means of production, it makes sense to explore whether articulation proficiency is differentially heritable *as a function of* the specific phoneme. Such a finding could impact on speech and language pathologists who could then consider the source of speech and language problems when designing intervention programmes. In order to unravel the environmental and genetic contributions to articulation proficiency, twin data can be used in combination with a modelling procedure described by two authors [3] which allows for a direct estimate of the degree of genetic versus environmental contribution to phenotypic variation. These authors have shown that direct estimates of heritability (h^2) and environmentality (c^2) – to adopt the terminology employed more recently [11] – can be obtained through implementation of a multiple regression methodology [3]. In their approach, each twin's score is regressed on (a) its cotwin's score, (b) an index of the degree of genetic relationship, and (c) an interaction term. What they describe as their ''augmented model'' appears thus:

$$C_1 = B_1C_2 + B_2R + B_3C_2R + A$$

Here, C_1 is the score for one twin, C_2 is the score for the other twin in the twin pair, R is the coefficient of relationship (eg., 1 for MZ twins, .5 for DZ twins), C_2R represents the interaction between C_2 and R, the B's correspond to the standardized regression coefficients associated with each of the terms, and A is the intercept. Using this regression equation, DeFries and Fulker argue that B_1 and B_3 are direct estimates of environmentality and heritability, respectively, and that the statistical significance of these coefficients represents the probability that the parameters they estimate are equal to zero. When applied to articulation data, this approach allows for the detection of heritable and environmental contributions to articulation proficiency. Moreover, when articulation scores are taken at the level of the phoneme, it becomes possible to determine whether heritable and environmental influences are at work in contributing to phenotypic variation within each phoneme, and to determine whether there are differences as a function of each phoneme.

The purpose of the present investigation was to apply the statistical modelling approach described [3] to an existing archival data set consisting of twins' articulation scores on a number of individual items. The test that was in vogue at the time of the original assessment (the beginning of the 1970s) was the Templin Darley Screening Test of Articulation [13], cited above. Although researchers have pointed out that the Templin-Darley has fallen from favor as a screening test [12], the Templin-Darley data remained valuable to us because they included speech samples on a small number of relatively difficult items. It was also the only instrument for which we had a large sample of twin articulation data. In any case, our use of the Templin-Darley instrument is particularly appropriate in light of its use in previous heritability research, allowing direct comparisons between current and previous findings.

Even though the data comprised a relatively small number of phonemes, it seemed unnecessarily cumbersome to examine heritability/environmentality across each and every Templin-Darley item. Common abilities are presumably involved in a number of different items (eg., the production of /r/ in different contexts likely calls on similar underlying mechanisms), so we decided to aggregate 'like' phonemes. Perhaps the most straightforward means of aggregation would be simply to 'add together' correct responses on items that contained the same phoneme. But phonemes are units of speech, and as such are not even potentially heritable; hence it would not make sense to combine individual phonemes. Rather, what are potentially heritable are the underlying anatomical structures, motor skills, and/or perceptual acuities needed for producing phonemic segments. Consequently, if the production of different phonemes derives from common underlying structures, abilities, and/or skills, then it would make sense to aggregate them according to these components, rather than according to their functional role in speech. Rather than attempting to specify a priori which underlying components might be common to several different phonemes, we believe that the most sensible aggregation criteria should come from the data themselves, based on empirical covariation.

MATERIAL AND METHODS

The present investigation involved two phases. In the first phase, Templin-Darley protocols were factor analyzed. The purpose and result of this analysis was to aggregate those Templin-Darley items presumed to share underlying mechanisms (eg., structures/skills/acuity) which are potentially heritable. It was, of course, expected that articulation of a given phoneme within different items, such as /r/ in "bird" and "arrow'', would share production mechanisms, as reflected by their loading on the same factor. However, it was not known whether phonemes differing in one or more contrastive features would load on the same factor. Indeed, our factor analysis of Templin-Darley responses represents, to our knowledge, the first attempt of its kind. In the second phase, phonemic-level articulation was no longer characterized by proficiency on individual Templin-Darley items. Rather, it was characterized by the ways that the items were aggregated, that is, in terms of the 'factor scores' obtained from the first study. Each factor score is presumed to reflect children's relative articulatory proficiency on one phoneme or phoneme set. The factor scores, then, were analyzed following the previously described regression procedure [3].

Derivation sample

The sample and articulation protocols used for this investigation were archival data which have been previously described [7, 8]. A brief description of the original sample and methodology is presented below.

Subjects

The subject sample consisted of 256 identical and fraternal twins and 125 of their singleton siblings who were selected from a larger population of twins participating in a longitudinal investigation conducted by the Louisville Twin Study. Where possible, both twins and their singleton siblings were included in order to maximize the sample size and uncover the most stable factor structure. Collectively, the sample consisted of 381 children ranging in age from 2;11 to 9;8. The mean age was 65.43 months. There were 194 girls and 187 boys. All children were white and, on average, came from middle-income families, although the entire socioeconomic range of families was represented.

Data gathering

Each child was individually administered the 1960 version of the Templin-Darley Screening Test of Articulation. As reported by the study cited above [8], the imitation method for eliciting a child's utterance was avoided except when the child did not know the word to be elicited by the stimulus pictures. All utterances were recorded on audiotape and were immediately transcribed using the International Phonetic Alphabet.

Data reduction

For each test item, only the target phoneme or phoneme cluster was scored. A child was given a score of "1" for correct articulation, and a score of "0" for any error, including additions, distortions, omissions, and substitutions. Thus, for each child there was a string of "1's" and "0's," corresponding to the accuracy of articulation of the target

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phonemes and phoneme clusters represented by the 50 items. It should be pointed out that due to this coding system, the following factor analysis was based on phi correlations. It is often argued that factor analyses should be conducted on data coded on at least an interval level. While this preferred approach is recognized, it is also noted that interval data are sometimes not available. Furthermore, Monte Carlo research has shown that factor analyses based on subinterval data, including those based on phi coefficients, produce results quite comparable to interval-level-based factor analyses, even when the scores have fairly unequal distributions [1].

RESULTS

A principal component-based, orthogonally rotated, factor analysis with iterations was conducted using data from the entire group of 381 children. Convergence criteria were achieved after 5 iterations. SES was statistically removed (cf. [8]). Using a scree plot and a minimum eigenvalue of 1 as criteria, a five factor solution appeared maximally efficient. Five factors accounted for 50.10 % of the original variance.

Table 1 - Factor structure: factor loadings of items from the Templin-Darley screening test of articulation

		Factors		
/r/	/ʃ, tʃ, dʒ/	/s-/	/θ, ð/	/l, j, w/
bi*r*d (.66)	*sh*eep (.52)	*sm*oke (.68)	*v*alentine (.41)	on*i*on (.46)
*r*abbit (.72)	di*sh*es (.63)	*sn*ake (.64)	*th*umb (.61)	*pl*anting (.61)
a*rr*ow (.69)	fi*sh* (.65)	*sp*ider (.71)	ba*th*tub (.50)	*cl*own (.62)
*pr*esents (.74)	*ch*air (.56)	*st*airs (.64)	tee*th* (.57)	*gl*ass (.68)
*br*ead (.81)	ma*tch*es (.69)	*sk*y (.70)	*th*ere (.47)	*fl*ower (.55)
*tr*ee (.73)	wa*tch* (.65)	*sl*ed (.48)	fea*th*er (.58)	*tw*ins (.42)
*dr*ess (.72)	*j*ar (.51)	*sw*eeping (.43)	smoo*th* (.56)	*qu*een (.41)
*cr*ayons (.75)	engine (.59)	*spl*ash (.40)	*thr*ee (.40)	
*gr*ass (.74)		*scr*atch (.40)		
*fr*og (.73)				
*thr*ee (.58)				
*spr*inkling (.54)				
*str*ing (.53)				
*scr*atch (.59)				

Note: Items were not constrained to load on a single factor and were counted as loading on a factor if the loading equalled or exceeded an arbitrary loading criterion of .40.

Factor structure matrix

The factor structure pattern shown in Table 1 represents the correlations between the individual items and the factors. The target phonemes within each item are italicized Each factor can be interpreted to represent children's generalized ability to articulate a particular phoneme or set of like phonemes. The first factor can be called an "/r/-factor" because it appears to represent children's generalized ability to produce /r/, regardless of context. All items on this factor contained /r/, either as an initial or medial singleton, or as part of a word-initial CC or CCC cluster. The strongest loadings were found in the single and dual consonant contexts, which may partially reflect an artifact of the scoring procedure. As noted by one group of authors [12], the scoring procedure for the Templin-Darley counts as correct only the responses that accurately produce all elements in the target cluster. Even though a response may represent /r/ correctly, it may still be scored as "incorrect" if another of the consonants is missed. Thus, children did not necessarily misarticulate /r/ in the cluster when they received a score of "0" for the cluster. Nevertheless, the fact that /r/-containing clusters loaded on the /r/-factor and not other factors, reveals that children who tended to accurately produce /r/ as a singleton, tended also to accurately produce whole clusters containing it.

The second factor did not clearly isolate a single phoneme, but consisted of /ʃ/ and /tʃ/ in initial, medial, and final positions, and /d / in initial and medial positions. This factor will be referred to as the "/ʃ , tʃ, dʒ/-factor". The fact that all three of these phonemes were found to load on a single factor suggests that they may share underlying production mechanisms. The most obvious feature in common is a linguapalatal place of articulation, with a fricative component. This finding alone justifies our empirically based approach to item aggregation. Had we proceeded with only functionally based aggregation, we would have considered each of these phonemes separately. In contrast, it appears that /dʒ/, /ʃ/, and /tʃ/ may involve many of the same underlying mechanisms.

The third factor was clearly one representing processes involved in the articulation of /s/ in word-initial CC and CCC clusters; /s/ does not contribute to this factor as a singleton because it is not assessed in singleton form. As with the /r/-factor, the word-initial CCC loadings were not as strong as the word-initial CC clusters. This trend would be expected for reasons noted above. However, it can at least be said that children who accurately produced word-initial CC clusters containing /s/ were more likely to accurately produce these, than clusters of either type not containing /s/. The fourth factor seemed to represent a "/θ, δ/-factor". Six of the seven loadings consisted of /θ/ and /δ/ in initial, medial, and final positions. The common production mechanisms here are most likely the linguadental place and fricative manner of production. Voicing, which serves as the contrasting feature for /θ/and /δ/, did not prohibit these phonemes from loading together. Interestingly, /v/ also appeared on this factor. It may be that /v/ loaded on this factor by virtue of its fricative manner and frontal place.

The last factor can be seen to be represented by "/l,j,w". Most prominently associated with this factor was /l/ in word-initial CC clusters. But also related were the semivowels /j/ and /w/. These latter loadings were somewhat surprising given the differences in place/manner of articulation, compared with /l/. However, /j/ and /w/ share with /l/ a within-consonant cluster assessment, as well as lingual involvement in combination with slight vocal tract constriction.

Heritability and environmentality: regression analysis

Application sample

Subjects

For the second part of the investigation, the subject sample consisted of only the 256 identical and fraternal twins from the first sample. Cross-tabulated by gender and zygosity, there were 72 MZ and 58 DZ boys, and 58 MZ and 68 DZ girls.

Procedure

Based on the Templin-Darley factor structure determined above, factor scores were calculated for each child on each phonemic factor. These scores were then entered into the equation cited above [3]. Due to the nature of twin data, each twin's score was entered twice following standard twin analytic procedures, once as the dependent variable and once as the independent variable.

RESULTS

Intraclass correlations for all five factors were calculated. These correlations can be found in Table 2. As can be seen, there is generally a drop in correlational magnitude from MZ to DZ twins, providing strong evidence of genetic influences. However, heritability appears to be mediated by phonemic factors, such that for some factors there appears to be greater heritability than for others.

Table 2 - Intraclass correlations as a function of phoneme type and zygosity

Phoneme type	Zygosity status	
	DZ	MZ
/r/	.55	.86
/ʃ, tʃ,dʒ/	.47	.74
/s/	.57	.79
/θ, ð/	.67	.86
/l, j, w/	.69	.76

Note: All correlations are significant at the $\alpha = .001$ level.

Results from the regression analyses allow direct assessment of the degree of heritability, as well as environmentality. Table 3 presents these parameter estimates for each of the five phonemic factors. Because the double entry procedure has been employed in this study, parameter standard errors tend to be underestimated. For this reason, it has been argued that the standard errors should be adjusted by multiplying them by the

Table 3 - Estimates of heritability and environmentality as a function of phonemic factor

Phoneme Type	Parameter	
	h^2	c^2
/r/	.62**	n.s.
/ʃ, tʃ,dʒ/	.54*	n.s.
/s/	.44*	.35*
/θ, ð/	.39*	.48**
/l, j, w/	n.s.	.61**

Note: Following [2], *p<.05; **p<.01.

square root of (df double entered/df single entered) [2]. This adjustment value asymptotically approaches $\sqrt{2}$ as the sample size increases. In any case, the one-tailed significance levels for each of the parameter estimates presented in Table 3 have been adjusted accordingly. One tailed significance levels were used because the parameter estimates were intentionally constrained to be zero or greater.

The results suggest that there are indeed differences in heritability as a function of phonemic factor. The phonemic factor most strongly associated with heritable components was /r/, in which 62% of the phenotypic variation in /r/ articulation can be accounted for by genetic influences. Environmental influences, in contrast, did not reach statistical significance for this factor. At the other end of the continuum, heritable mechanisms were not found to account for a significant portion of the phenotypic variance in /l, j, w/. Rather, the majority of variance in this factor, 61%, was associated with environmental influences.

DISCUSSION AND CONCLUSIONS

As we see it, the present article makes two important contributions to the extant literature. Among the most basic findings was that children's articulation proficiency on specific phonemes tended to be differentially related to proficiency on other phonemes. For example, production of /l/ in a word-initial CC cluster was more strongly related to production of /j/ than to the production of, say, /θ/, as implied by the common loadings of /l/ and /j/ on the same factor. The existence of separate common factors implies that phonemes which share a factor in the statistical sense, may share underlying production components as well. One practical implication of this finding is that to the extent that successful articulation training transfers to other phonemes, the degree of transfer ought to be linked to the degree of association of the underlying articulatory components. Some evidence for this point can be found in one study from the early 1980s [10], in which training on a particular phoneme within a cluster, such as /s/, did not generalize to other phonemes such as /r/.

The second major contribution of this study, and the most important, is the demonstration of differential heritability as a function of phoneme type. Quite simply, production of some phonemes is more genetically determined than others. In particular, it appears that variation in the production of /r/ is largely a result of genetic variation, while variation in the production of /l, j, w/ appears to be relatively independent of genetic influences and to be strongly influenced by environmental variation. The finding that /r/ and /l, j, w/ were primarily the result of genetic and environmental contributions, respectively, should not be taken to mean that variation in articulation proficiency is *determined* by these sources of influence. We only wish to argue that these were the single largest sources of variation. Indeed, at best only about 60 percent of the phenotypic variation arises from either one of these sources alone, which leaves a great deal of variation yet to be accounted for.

While we find these results interesting in their own right, the relative importance of genetic and environmental contributions to articulation proficiency has some important implications for the field of speech pathology. The most straightforward implication is that intervention difficulty may covary directly with heritability, and inversely with environmentality. Thus, children's misarticulation of /r/ may be more resistant to intervention than, say, /l/, all else being equal.

Unfortunately, this implication has been difficult to verify. Surprisingly little empirical literature has reported on the relative difficulty of training these two phonemes. In fact, a search of the literature has revealed no direct comparison of /r/ versus /l/ intervention success rates in any English-speaking population. Professional speech pathologists have provided at least anecdotal support for this notion. On the other hand, we do not wish to argue that speech pathologists should give up on training phonemes which have highly heritable components. Quite to the contrary, we support the position, that "behavior genetics research tells us about *what is* - the genetic and environmental origins of individual differences in a population — not *what could be* — whether, for example, a particular intervention will work. The two should be viewed as complementary. Knowledge about *what is* can help to guide research concerning *what could be*" (p. 9) [11].

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