Invariance of effort in child speech breathing as a 'fast and frugal' heuristic for the acquisition of durational phenomena in stress-accent languages

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ABSTRACT

We do not need to imagine children becoming sensitive to and then imitating the complex set of durational processes found in English (and other Germanic languages) in order to acquire them. English, like many other systems that must remain viable through successions of reproductive cycles, has straightforward solutions to its developmental challenges embedded within its structure.

In particular, a child learner's response to the distinctive demands of stress-accent, implemented by a child's production system, generates many of the 'durational' phenomena that have resisted satisfactory explanation in terms of their timing. As a result, the phonetics of English becomes more coherent than previously considered.

1. INTRODUCTION

English phonetics contains the following two unresolved problems, among many others:

1. Is rhythmicity a consideration in the production of normal speech?

The outstanding evidence in favour of a rhythmic basis to spoken English is the phenomenon of foot level shortening. This is taken as evidence that speakers aspire to isochrony.

2. Are the three criteria which can define the tense/lax vowel classes independent or connected?

The classes can be defined by articulation (degree of oral constriction), by duration ('long' or 'short' in certain contexts), or by phonotactics (lax vowels always being 'checked'). The fact that these yield identical inventories suggests, *prima facie,* a connection, but one has not been established.

I will discuss these questions with reference to RP, but the arguments extend naturally to other varieties of English and other Germanic, stress-accent languages.

2. APPROACHES TO ACQUISITION

Children are assumed to become sensitive to the existence of these and other phenomena in the linguistic environment (such as VOT distinctions, compensatory shortenings and so on), and then to imitate them. Direct control of timing is currently believed to play a central role in their production.

However, as our understanding of the range and complexity of such processes deepens, this account seems increasingly implausible. It is also striking that having conceptualised so many phenomena as durational and then (not unnaturally) assumed that timing is primitive to them, we have been unsuccessful in modelling any such process in natural terms. (E.g. [1] and [2].)

Fielders don't position themselves to catch cricket balls by calculating complex trajectories and paths of interception. Instead, they use a simple heuristic relating the angle of their gaze to the moving ball (although they are generally unaware of this) [3]. Similar 'short cuts' making use of the structure of the environment to meet apparently complex challenges have been labelled 'fast and frugal heuristics' by Gigerenzer [4].

The possibility that timing may not be primitive to an apparently 'durational' process is only rarely put forward, and then usually with some hesitation because no plausible alternative basis for the phenomenon can be identified. The proposal below, for a number of such alternative mechanisms, follows Catford [5] in focussing on the aerodynamic phase of speech and draws on recent developments in our understanding of stress accent, speech breathing and the acquisition of motor skills.

3. PULSATILITY AND EFFORT IN STRESS-ACCENT

Increased loudness and duration are now understood to be reliable correlates of stress in English (with pitch movements seen as part of a separate intonation system - docking on to prominent syllables but not defining them). The experiments which have established this (e.g. [6]) do not prove that these correlates are the result of extra respiratory system effort, but the results are consistent with this well established native speaker intuition.

Finnegan et al. [7] have now provided the first instrumental evidence for this, contradicting the conclusions drawn by most modern investigators from the evidence that existed previously (e.g. [8]). They found that the respiratory system plays the primary role in increasing

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sub-glottal pressure not only during sustained increases in the intensity of conversational speech, but during transient ones related to emphasis as well.

It is reasonable, therefore, for us to again regard adult speech breathing for English as being pulsatile (as many phoneticians have always maintained). Can we assume that the same is true for the speech breathing of children?

The adult pattern of speech breathing shows a shift from net inspiratory to net expiratory muscle pressure as the recoil pressure of the lungs changes with decreasing volume. However, for children Netsell et al. [9] derived hypothetical functions showing that over the normal range of speech 4 year olds only speak with net expiratory muscle pressure.

The development of respiratory system pulsatility by a child would therefore only involve a straightforward adaptation of the pattern of muscular recruitment already in use. This seems a simpler and more plausible response to the prominence demands of stress accent than any alternative based on laryngeal adjustment and invariant respiratory drive. (For further reasons to believe this, see [10].)

The domain of pulsatility will be the foot. A prototypical foot consisting of a syllable containing a full, stressed vowel followed by zero, one or more syllables with reduced vowels, will start with a single pulse of respiratory system effort. What, though, will determine the degree of effort applied? Will it vary according to the total number of segments in the foot, to their nature, to the number of syllables, to a combination of these, or on some other basis altogether?

Speech breathing is an extremely complex motor skill. For the performance of speech it has to be embedded within a larger scheme involving simultaneous movements of the larynx and upper articulators, and cognitive activity. For English to be learnable, then, there are significant advantages to its speech breathing being simple.

We should therefore begin by modelling pulsatility in English with the simplest assumption, that of isoergonism: the pulse associated with each foot being produced, *ceteris paribus*, with the same effort. Put another way, each foot will have the same quantum of initiator energy associated with it, a suggestion already advanced by Catford [5]. Netsell et al.'s [9] further conclusion – that speech breathing in children is at least twice as effortful as in adults – reduces the sensitivity required for such an approach on the part of the child, and therefore increases its plausibility. (If our assumption fails to produce realistic consequences we could consider more complex alternatives.)

4. FOOT LEVEL SHORTENING WITHOUT A RHYTHMIC BASIS

A child's progress towards adult-like English 'rhythm' depends as much on vowel reduction as on the deployment of stress [11]. On perceptual grounds, syllabic status is accorded to a sequence of a reduced vowel flanked by consonants, and this means that feet are potentially multisyllabic.

However, from the perspective of the respiratory system vowel reduction appears rather differently. As Catford [12] points out, a weak syllable in English involves a minimal opening of the vocal tract during its vocalic 'nucleus'. Aerodynamically it can be seen as just an 'open transition' between consonants, with the 'vowel' sound a marker of the fact that the articulation of the onset consonant is completed before that of the coda consonant(s) begins. This contrasts with the overlapping articulations of a 'close transition' between consonants, more usually called a consonant cluster.

From a respiratory system perspective there is no significant difference between the production of syllables with increasingly complex final consonant clusters and of feet with increasingly extended tails. Both just involve the accretion of additional elements to a strong initial syllable.

So if a central aspect of the production of a foot is an isoergonic pulse of respiratory system effort, a natural account of foot-level shortening emerges which bypasses syllables. As the number of elements following the nucleus of the initial stressed syllable increases, the limited respiratory system energy available for the production of the foot needs to be redistributed and the proportion devoted to each element reduced. Thus while the overall duration of the foot will increase as a result of its greater number of elements, the durations of the elements themselves will decrease. A change in relative timings will be a readily perceived by-product of the process, but not its controlling parameter. Catford suggested this might be the case for adults [5]; it seems even more likely for children.

5. TENSE AND LAX VOWELS

At 30 months English speaking children are producing /i:/ and /I/ with reliable qualitative distinction but without adult-like durational differences [13]. How do these differences emerge?

The lingual articulations of these and other tense-lax vowel pairs are characterised by a smaller area of maximum constriction for the tense member than the lax. Catford [5] distinguishes them as approximants and resonants respectively. His approximants have non-turbulent airflow when voiced, but turbulence appearing when the airflow increases with voicelessness. His resonants have a lesser degree of stricture that does not give rise to turbulence in either condition.

To my knowledge no data exist on the constriction sizes of children's vowel productions. It would be rash to infer solely from the reduced size of children's oral cavities that their constrictions will be smaller than the equivalent adult versions, however the first formants of child /i:/ and /u:/ are significantly higher than the adult values. Other things being equal, this does imply a smaller XSA.

The data on the aerodynamics of child speech are not consistent, but at comfortable intensity levels children seem to speak with slightly higher tracheal pressure (Pt) than adults and with either similar or slightly reduced airflows. Increasing the loudness of their speech is associated with proportionately greater increases in Pt.

If no compensatory changes are made by the child, then what effect will the greater airflow associated with the increased respiratory effort of stress accent have during a tense vowel? The XSA of its constriction is closer to the critical boundary between laminar and turbulent flow than the adult equivalent, so the consequence may be turbulent sound production. This is an unacceptable quality for a vowel, so a compensatory change must be made. The natural response will be to increase resistance at the glottis to limit airflow, a manoeuvre that can be executed more or less independently of other source properties [14] and which is similar to the aerodynamic accommodation seen in adult speech in analogous situations [15].

(Such a response also explains the intuition of some phoneticians that 'tenseness' extends to the vocal folds [16], even if this might sometimes be an echo in the adult of a strategy adopted and only required by the child.)

Operating within a system of isoergonic pulses of respiratory system effort, such an increase in the overall resistance of the vocal tract for tense vowels would motivate their duration to increase, at least in stressed contexts.

A potentially large increase in airflow due to stress accent will have different consequences for lax vowels (resonants). Children have a small lung capacity (at 4 years, about a quarter of the male adult norm) and expend a greater proportion of this on each syllable. Were stressed lax vowels to appear in open syllables then loss of air would limit the length of a child's utterances.

However, like every language, English must be suitable for use by its speakers at all stages of their apprenticeship. The phonotactic constraint that lax vowels are always 'checked' by an immediately following consonant limits the potential emptying of the reservoir of air. This makes it possible for otherwise aerodynamically unstable circumstances to be accommodated by children. The system will be motivated to make the duration of a lax vowel as short as is consistent with the requirement to expend the isoergonic respiratory pulse.

This account makes the articulatory, durational and phonotactic properties of tense and lax vowels coherent. It also provides a phonetic basis for Trubetzkoy's *silbenschnittkorrelation*, with the latter's understanding that the tense-lax distinction is not primarily a matter of length but of the energy distribution within the syllable [17].

Finally, with respect to word-final weak vowels and diphthongs, we can note the intuition of native speakers that the former are 'low energy' sounds. If we take this to refer to the respiratory effort expended on them, then this implies a heightened laryngeal resistance for their production. The targets for the glides in the centring and closing diphthongs may have a similar specification and so serve to stabilise their aerodynamics in open syllables.

6. OTHER PHENOMENA

Development of these arguments provides natural explanations for many 'durational' phenomena in English, including the pattern of VOT and aspiration seen in mature speakers, the pattern seen developmentally, pre-fortis clipping, and so on. It also suggests an explanation for the location of P-centres: at the point of maximum expiratory effort of the respiratory system, coupling very naturally, of course, with finger tapping . (Acoustic criteria coupled to this point in time would be developed by the speaker, and would then be available to identify P-centres in externally produced material.)

7. CONCLUSIONS

Examining the effect of stress accent from a developmental perspective, with an understanding of the aerodynamic, physiological and motor constraints that speech being embodied in a speaker places on the system, may explain many of the phonetic and phonological patterns that distinguish English and other Germanic languages from non stress-accent languages.

Many of these phenomena have been analysed as durational. In mature speech timing criteria probably develop to control them. However, developmentally timing may be epiphenomenal. The nature of stress accent as implemented by a young speaker may be a fast and frugal heuristic for the acquisition of the distinctive characteristics of spoken English.

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