

Vocalization frequency as a prognostic marker of language development following early cochlear implantation

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Abstract

Despite their potential significance for later linguistic outcomes, early aspects of vocalization had been seriously undervalued in the past, and thus, minimally investigated until relatively recently. The present article sets out to critically examine existing evidence to: i) ascertain whether vocalization frequency (volubility) posits a plausible marker of cochlear implantation success in infancy, and ii) determine the clinical usefulness of post-implantation vocalization frequency data in predicting later language development. Only recent peer-reviewed articles with substantial impact on vocalization growth during the first year of life, examining sound production characteristics of normally hearing (NH) and hearing impaired infants fitted with cochlear implantation (CI) were mentioned. Recorded differences in linguistic performance among NH and CI infants are typically attributed to auditory deprivation. Infants who have undergone late CI, produce fewer syllables (low volubility) and exhibit late-onset babbling, especially those who received their CIs at the age of 12 months or thereafter. Contrarily, early recipients (before the 12-month of age) exhibit higher volubility (more vocalizations), triggered from CI-initiated auditory feedback. In other words, early CI provides infants with early auditory access to speech sounds, leading to advanced forms of babbling and increased post-implementation vocalization frequency. Current findings suggest vocalization fre-

quency as a plausible criterion of the success of early CI. It is argued that vocalization frequency predicts language development and affects habilitation therapy.

Introduction

Dwelling on the topic of the prelinguistic development, we would eventually experience considerable complexity in differentiating between features identified with numerous sorts of utterance patterns produced by infants. One of the merits of securing early access to cochlear implantation (CI) is that the empirical manipulation of auditory input is facilitated, allowing more straightforward interpretations and reducing any contaminating effects that may arise from confounding variables. In doing so, we would also prevent various diverse factors from causing inaccurate results to turn up. We hitherto endeavor to investigate the degree to which a certain area of data, non-other than vocalization frequency or volubility is essential as a criterion for determining CI success. Also, to see whether it is a means of foretelling subsequent linguistic faring levels according to the databases Google Scholar and PubMed/Medline. If we approach CI promptly, we will be able to form useful conclusions on defining the results of auditory manipulation on pre-linguistic progress more easily. It is suggested in this paper that vocalization frequency or volubility can forecast early CI success in subsequent language progress. Vocalization frequency may clinically be utilized as a measure of an early-stage success for CI, and of subsequent language progress.

Early cochlear implantation

Children and toddlers implanted with CI's all over the world have vastly increased to 80.000 and over lately, still rising higher.^{1,2} In view of this, a considerable number of modern and highly developed elaborate techniques relating to molecular genetic^{2,3} examination methods and lately discovered ways of conducting audiometric processes⁴⁻⁶ were generated thus rendering scanning and prompt observation procedures assessing inherent deafness possible within the very first, short time period of the infant's life. The universal phenomenon of congenital deafness was lately said to fluctuate between 0,2 and 3 instances occurring in natural birth in industrial parts of the world. Figures are higher in evolving areas globally.^{2,3,6}

Hearing is improved by instruments such as CI's that increase the sound output which is carried into the auditory nerve and thence to cortical sections. These instruments convey an immediate stimulus to the auditory nerve, passing round the non-function-

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Key words: Volubility; Cochlear implantation; Language development; Infants; Auditory perception; Early vocalization.

Contributions: the authors contributed equally.

Conflict of interest: the authors declare no potential conflict of interest.

Funding: none.

Received for publication: 3 October 2018.

Revision received: 2 February 2019.

Accepted for publication: 8 April 2019.

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Audiology Research 2019;9:217
doi:10.4081/audiores.2019.217

al segment, not affecting any parts of the transmission area between the outer ear and the auditory nerve and acting as surrogate electrical stimulus supplier to the auditory cortex enabling it to process this stimulus further on. The qualities of the stimulus differ from their acoustic stimulation counterparts, but they retain the basic essence that governs standard cochlear functioning code.¹ Hearing impairment owing to either conductive or sensorineural causes, when manifested in the middle and/or inner ear (ossicles/*dead regions* in the cochlea respectively)^{3,5} can be made up for through cochlear implantation. By getting round the weak region and focusing on the auditory nerve, we will produce a subject-to-stimulus-area to which sound energy is conveyed.

We could take for granted that linguistic quality levels sufficiently depend on disturbed or not, auditory experience between hearing impaired (HI) and normally hearing (NH) infants. As a significant consensus of opinion has it, the progress in produced and perceived language can be foreseen in a promising manner when combined with timely CI as opposed to its taking place later in the child's life.^{2,7,8} However, these documented data offer us the chance to utilize CI for the purpose of gaining the best possible benefits we could. These outcomes include the perceptual understanding of complex speech sounds and the phonatory/articulatory structures that formulate and coordinate early vocalizations.⁹ Auditory input and auditory self-feedback share a high potential, lately becoming popular for investigation purposes again.^{1,8,9} We may well be in for comprehending more substantially the lines of action required for the progress of infant vocalization in both, NH and HI groups.

The standards of empirical facts are extremely high, and we could rest assured that prime testing experimentation routines are available and that if we resort to CI at a later stage, this would be direct and accurate. This is very important and cannot be disputed. We have to bear in mind the three principal steps before we implement CI: diagnosis, prognosis, intervention. Thence, all pediatric ear-nose-throat (ENT) teams are ready to commence the post-implementation practice.

Having implanted the CI's, ENT teams monitor the infant's CI experience time, a particularly difficult task, featuring complications of unique nature, when it comes to evaluating facts such as *e.g.* limited ability of articulate speech in infancy. Well founded and credible measures should be taken when applying CI's, for chances of successful or unsuccessful interventions are indeed critical, taking into account what CI's really offer in the area of vocal gains when applied early.^{2,10} Within the post-operative time period necessary for the infant's convalescence and restoration to health, tools are needed by which we may foresee and be aided in determining coefficients of receptive and expressive language progress, as long as intercession on the part of ENT teams and CI implementation are prompt and reliable.

In numerous studies detailing auditory-guided speech production growth at a post-CI early application time, vocalization frequency has been recognized as a clinical tool and its value has been underlined. Reports elaborated on by Warner-Czyz *et al.*,¹⁰ during their investigation course in lexical accuracy at a post-CI early application stage, claim rapid rise in phonetic vocalization frequency rates from 65 to 334 vowels during pre- to post-implementation periods. This established escalation in the recorded rates of phonetic performance is ascribed by the above-mentioned essayists to the children's improved auditory acuity. There have also been parallel results presented by Dettman *et al.*,⁷ detailing positive volubility conclusions as opposed to normal hearing counterparts. These rates occurred even in infants who had not completed the age of 12 months. Ertmer *et al.*^{11,12} carried out a set of studies whose findings were relatively corresponding to NH counterpart

rates, particularly in instances in which CIs had been applied to the young one before completing 3 years of age and having previously taken part in oral habilitation programs.

According to Fagan who dealt not long ago with the hypothesis on auditory feedback being the principal motivation factor to early vocalizations, a model assessment is of significance featuring NH counterparts and most certainly HI infants.¹ For this purpose, she juxtaposed frequency in pre- and post-CI-implantation patterns, thus verifying that CI implementation is a decisive milestone in linguistic tools for HI children, rendering their language development in terms of vocal expression like that of their NH counterparts. Fagan maintains that the HI toddlers are assisted by CI in being given auditory means of approach to their own voice (vocalizations created by themselves) and to the vocalizations of their caregivers.¹ Cochlear implantation and auditory approach back up each other by drawing attention from their domain. The former reinforces the latter, by attracting attention from their environment, hence enabling the attribution of meaning to the sounds produces, accelerating closure of the pre-existing developmental gap between HI and NH peers.¹³

Prelinguistic vocal growth

Within the period of the months coming before the infant utters words, early features in language arise, developing in a global and foreseeable sequence of vocalizations and gibbering which apparently plays a very significant part in later language development.^{1,2,11,14} Despite the fact that some models still present had been considered to elaborate on linguistic development issues in bygone days, only little information was obtainable connected with pre-linguistic vocal growth progress, practically until quite lately.¹⁵ The fact that early sound origination indicates a pragmatic issue for the whole time of the infant's age, explains the reason why notional hypotheses arose and general improved ideas were created today.

It is most significant to be pointed out that the main axiom identified with the substance of vocal development is verified by a host of forerunners to the origin of speech, beginning with voices comprehended in part and later continuing with coherent syllables, eventually leading to creation of words within the last six months of the infant's first year of age.¹ Amongst the multitude of precursors to speech, beginning from loosely-shaped, partially-intelligible utterances and followed by well-formed syllables and word production (which typically occurs during the later second half of the first year of life) vocalizations include all types of non-vegetative sounds, excluding reflexive behaviors (*e.g.* crying) as well as those tied to affective states (*e.g.* laughing and crying).^{1,4} The progressional landmark in language growth consists of the vocalizations during infancy, which gradually diminish, eventually to be replaced by speech-sound vocalizations.¹¹

Vocalization frequency represents a major clinical essence connected with the growth of early speech. It is identified with the amount and/or frequency of sounds produced, irrespective of the form of vocalization or of the voice.¹⁶ A pre-linguistic measure unit for vocal ability is the assessment of vocalization frequency. Vocal ability is related to various environmental and biological conditions but quite lately neuroconstructivist and procedures based on acquired experience have related to it.¹⁷

The reason why there is a driven urge to examine how speech-sound production takes place is still non-specific.^{1,15-20} Various academic works of limited volume and of rather illustrative character have focused on research to do with vocalization frequency as a matter of tradition.²¹ This may relate to the procedure of set-

ting early measure units of speech–sound creation down on record, something that accounts for the inborn systematical restrictions connected with it. However, estimation of volubility given details requires laborious effort in time and an all-wide range of real-life naturalistic language records.²² On the other hand, the given amounts of pre-speech vocalizations are time after time subject to changeability (*e.g.* rising and falling of the levels at which they turn up). These amounts are also connected with the socioeconomic standing (SES),¹⁷⁻²³ caregiver interaction^{16,17,20} and various aspects contingent on one another, linked with intricate issues on neurodevelopmental progress.¹⁷

It has been claimed in detail that infants of needy family backgrounds, *i.e.* low SES,²³ whose vocalization course may be affected by surrounding conditions present lower volubility levels and this is indicated by several articles published. Since many children of poor SES in their household get in touch with their caregivers taking care of them less often than others, the amounts of vocalizations produced are lower, owing to the poor level of contact with their parents or other principal caregivers who take care of them.¹⁶ None-the-less, it is worth-noting that several studies underline the significance of the way the endeavor to back up the infant on the part of the parents or caregivers fluctuates in connection with the manner in which the infant's real language development level gets on.^{14,17} The learned investigators point out that these two aspects counteract each other, as they both present an empirical conclusion, thus rendering it hard to take one or another course of action in view of the absence of the relationship between cause and effect as far as these two counterpoised notions are concerned.

Although the above-mentioned drawbacks relating to the mode of proceeding with a specific course of action are there, the pre-speech development comprising the results in low and high vocalization frequency values correspond to sub-categories such as Down,²⁴ Fragile X Syndrome,¹⁸ autism spectrum disorder,^{22,25} childhood apraxia of speech,²¹ congenital cleft palate and hearing impairment.^{1,11,12,26} More specifically, volubility data provide a valid and valuable measure for setting a point of departure between important aspects of typical and divergent language acquisition, thus enabling the clinical differentiation between children who exhibit typical speech sound development and those who present a greater risk for developing language disorders.

Current methodology for measuring vocalization frequency

Protophones represent a measure of vocal progress of prime interest in estimating vocalization frequency information. They are usually employed in coding children's vocalizations and utilized as a class of sound units characterized by their primitive (prelinguistic) properties.^{5-8,27} Therefore, protophone vocal frequency corresponds to the amount of protophones created per unit times. Protophonic forms constitute in part a child's infra-phonological domain and they essentially differ from complete speech sound in terms of phonatory and articulatory/acoustic parameters.²⁸ This domain of the human sound system has to do with the potential of a whole category of vocalizations within the infant's first year of age.²⁸

The intraphonological properties of protophones bring a real-life priority order of vocalizations into being, amidst which canonical babbling sets types of higher developmental standards of further stages. Canonical syllables comprising these forms of identical babbling stand as *phonetic building blocks for words*^{21,29} and roughly as from Consonant-to-Vowel transitions. Command of

these early forms is significant for acquiring the phonetic ability and diverseness required to creating words within the child's first year of age.¹

Apparently, these worldwide specifications seem to be simple but, in an endeavor, to form a more precise conclusion as to a child's phonetic expression, protophone-coding reference points are needed for which there is no global unanimity of opinion. Oller for example, is an advocate of protophone–coding founded on auditory sensations.⁵ However, if a sheer acoustic analysis procedure is blended with an auditory analysis counterpart, both to do with speech analysis carried out through software programs such as Praat,³⁰ may turn out to be especially useful, providing ample evidence lying within speech – creating systems.

According to Stoel-Gammon,³¹ all consonants except glottals and glides as true consonants, whereas Chapman *et al.*³² refer to include glottals as consonants in their work. The authors also proposed the true canonical babbling ratio (the number of true canonical syllables divided by the total number of syllables), as an improved version of the canonical babbling ratio (number of canonical syllables divided by total number of syllables) that had been previously proposed by Oller *et al.*¹⁵

It has already been detailed, that vocalization frequency may functionally be addressed as the number of utterances vocalized by a child per minute, thus referring to further linguistic progression.²⁶ The global vocalization progress stages NH infants go through, present an average volubility rate between 1.3 and 11.3 vocalization percentages per minute when they are six months old but these frequency values are subject to variation due to unforeseen circumstances.¹⁹

There has lately been dispute and speculation connected with how infants get on with volubility and to what extent it could be employed as a unit to assess group membership identification ratios between NH and HI infants. Bygone works present inconsistencies that restrain us from rendering the structure of volubility totally functional in view of the issue of hearing impairment. Earlier notions widely assumed that vocal sounds such as babbling, were mainly reflexive and, thus, vocalizations produced by NH and HI infants were expected to be similar throughout their first year of life.²⁸ Lately, academic investigation revealed parallel invariable volubility values in sound sequence patterns in order of time, deriving from HI and NH groups which ranges between 2.5 to 18 months of the infants' lives.^{4,33} Subsequent reports,^{34,35} recognized lack of hearing as a factor that either caused a notable developmental delay (of up to a year, according to Oller),²⁸ or a vocalization decline in severely-to-profound HI infants after the age of 6 months, which signifies the onset of a less conspicuous protophone category, namely canonical babbling.

The conclusions drawn hitherto rendered the issue of reliability of auditory perception the central point of attention as an elementary aspect to pre-linguistic development. Since there is inadequate research evidence suggesting that the reduced number of utterances created by HI infants is a fact, by the same token there are studies that have confirmed corresponding standards between HI and NH children as well. There are opinions to the contrary however, and dissimilarities passed on in other articles whose perspective is that HI groups present *hypervocal* susceptibility when juxtaposed with their NH peers.⁴ Regardless of the absence of explicit, illustrative investigation of the connection between early vocalizations and linguistic acquisition and progress, it appears, more and more often, that early vocal sound–creating issues comprise credible forecasters of attaining perceptual objectives associated with later–on–developed language patterns (*e.g.* expansion of vocabulary immediately corresponds to vocalizations happening within the age of infancy more often).

Studying volubility through protophone production rises the reliability of the method since the study of protophone productions is a well-established approach for the study of infant speech development. This approach provides an evidenced-based practice for the acquisition of canonical syllable control which is an essential linguistic component for higher expressive vocabulary skills and low reading levels can be explained by poor expressive vocabulary. However, low performance outcomes prompt to abnormal speech creation and to following language anomalies with subsequent academic failure in general. The aforementioned articles combined put volubility forward to function as a developmental guide throughout the infant's age. This guide may be at the disposal of ENT teams for measuring the positive results of a CI process and foreseeing linguistic progress further on.

Conclusions

The total number of the articles and the entire information details included hereby, stressed the crucial part of auditory feedback in the commencement phase of early vocalization frequency, alias volubility. This part has been ascribed to cochlear implants and the infants who receive them are the leading protagonists in this particular paper. Vocalization frequency levels are lower than those of the NH group within the pre-interventional period and the approach to cochlear implants was advantageous to numerous vocalizations. The outcomes following application, presented parallel speech-creating abilities in NH counterparts. This detail was set down on record roughly during a 4-month period of the CI being switched on, something very significant for the prompt commencement of the oral adjustment sessions carried out by speech pathologists.

The present paper contributes towards a growing body of literature which affirms the plausibility of sound production quantification methods (volubility) as prognostic markers of speech and language development, by setting the focus on CI infants and their post-operative linguistic success. Vocalization frequency stands as a priceless, reliable clinical marker for faring results and, eventually, as a fore-running index for adult / mature articulate language creation and its credibility is confirmed. Moreover, it depicts a good form of *modus operandi*, for estimating and measuring most favourable values of CI success by specifying post-interventional objectives set, competence norms, renewed views on scanning the developmental course of communication and continuity of care. To the best interest of the infant, steps should be taken so that recipients get the utmost out of CI's in their convalescing time and for the early duration of the CI empirical period.

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