Singing from infancy to puberty: an affront to laryngeal physiology or an opportunity?

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Abstract
The acquisition of musical skills is a natural process for children and wide evidence supports positive effects of music-related activities on their emotional regulation, mood and cognition. By the age of one year, the child begins to imitate songs or simple melodies and his musical skills progress during infancy until he becomes able to sing in tune and maintain a consistent rhythm, allowing him to participate in group music activities, such as choirs, bands, or classroom musical games. On the other hand, singing is a challenge to the fragile anatomy of the vocal apparatus of the child and vocal pathologies are very common in general children population. Evidence on this topic is very limited, but two studies support lower levels of dysphonia in the young singers. A proper musical education is of course the best way to introduce the child to singing through the discovery of the voice as a means of expression, without inducing tension or effort in the vocal production apparatus. Particularly during the voice change in puberty, a careful management of the singer's voice is required from the singing teacher, according to progressive voice mutation. Anyway, at the first signs of vocal fatigue, it is important to refer the child to an ENT or phoniatric evaluation and, if necessary, speech therapy.

Keywords: *Speech and voice disorders, Children, Singing development, Speech and voice therapy, Voice mutation.*

Children and Music

Music, instrumental or vocal, represents a universal human behaviour, all over the world. Several studies confirm that singing and other musical activities are often an integral feature of pre-school children's lives, both at home and in their local communities (Papageorgi et al., 2022). Even before being born, the baby, still in the mother's womb, is cuddled by the mother's singing. Responses to vocalization are documented between the 22nd and 24th week of fetal development (Woodward et al., 2017). Undoubtedly, if spoken language can be considered the most efficient means of supporting human communication, musical language is certainly the one that best conveys feelings and emotions, as confirmed by several studies. Confirming this is the maternal caress which - in the context of a serene motherhood - is carried out in a substantially musical way. Infants pay more attention to the wider pitch range of motherese (the special sing-song way in which parents vocalize to their infants) than to the typical of regular speech (Cooper et al., 1994).

Wide evidence supports positive effects of music-related activities on emotional regulation as well as on mood, stress reduction and social behaviours encouragement in children (Grebosz-Haring et al., 2024). The activation of several neural networks in musical activities, including the midbrain, area involved in the management of emotions and motivation, has been demonstrated by means of neuroimaging studies as well (Panksepp et al., 2002). Beneficial effects of musical abilities acquisition have also been observed in the fields of cognition, improving concentra-

tion, memory, coordination and language acquisition (Speranza et al., 2022).

Evolution of musical skills in children is a fascinating developmental process: infants around 6-9 months begin to move rhythmically to music, such as bouncing or clapping. They also react emotionally to music, showing excitement or calmness depending on the tempo and type of sound.

By the age of one year, they may begin to imitate songs or simple melodies they hear. At 2-3 years they begin to imitate - with approximation regarding rhythm and melody - the songs they hear from caregivers, shows or toys. At preschool age children's singing becomes more tuneful, and they can match pitches more accurately. As children start school, their ability to sing in tune and maintain a consistent rhythm improves significantly, allowing them to sing songs with a wider range of notes and more complex rhythms. They can sing songs with a wider range of notes and more complex rhythms, often participating in group music activities, such as choirs, bands, or classroom musical games. This teaches them collaboration, listening skills and the ability to follow a conductor or leader. During middle childhood most children can sing in tune with greater accuracy and across a wider vocal range. Their pitch-matching ability improves, allowing them to sing more complex melodies. With formal training, children at this stage start to develop vocal techniques such as breath control, articulation, and resonance.

Based on these considerations, singing from infancy needs to be considered as more than a simple opportunity and it must also be accounted into the frame of the development of larynx from the childhood to adolescence.

The pediatric larynx

On the other hand, singing is a challenge to the fragile anatomy of the vocal apparatus of the child due to several reasons:

- vocal fold length is smaller: in the child under one year of age the mean total length is 7.7 mm for males and 7.4 for females, but the muscular (vibrating) portion of the chord is much shorter: 4.9 for males and 4.4 mm for females. Subsequently the vocal fold will grow 0.7 mm / year (Rogers et al., 2014) with a progressive increase in the muscular component compared to the cartilaginous one,
- the layered structure of the vocal folds is not differentiated in newborns and young children and there is no ligamentous structure in newborns, with an immature one emerging between the age of 1 and 4 years (Sapienza et al., 2004),
- the infant larynx, in addition to being smaller, is more compact with less possibility of tilting of the thyroid cartilage on the cricoid, leading to less possibilities of frequency regulation,
- the smaller dimensions of the cervical tract result in a smaller amplitude of the resonance tract. The consequences concern not only the obvious reduction of signal amplification, but also the decrement of the sluggishness of the air column that in adults has facilitative effects on chordal vibration (Titze 2006).

Such features of the prepubertal larynx expose children and adolescent singers to laryngeal pathologies, even more than adults. As in adults, the nosological mechanisms are derived from mechanical stress in phonation: tensile stress (required for pitch increase) and impact (collision) stress: both have the potential to damage the epithelium of the vocal folds, also taking into account the higher fundamental frequency of children (Fuchs et al., 2008).

On the other hand, this condition of laryngeal fragility puts at risk of laryngeal pathologies regardless of singing activities. Vocal pathologies are very common in general children population (6–23% of children according to the Garcia Martin study) mainly due to vocal effort. Phonotrauma may occur because of psychosocial factors such as hyperactivity or impulsiveness, besides previous history of excessive crying, which are rather common among the child population. Even during leisure activities children frequently increase their voice intensity, resulting in laryngeal effort and in cervical muscle tension. Males appear to be more exposed to vocal pathologies, due to a more impulsive ed aggressive

behaviour during childhood. These vocal habits characterize hyperkinetic or musculoskeletal dysphonia in children leading to vocal nodule development (Martins et al., 2012).

So, what to think? Does singing in pre-pubertal age protect or expose to vocal pathologies?

Scientific research is extremely poor on this topic, with only two studies. The first paper (Williams at al., 2005) has observed that choristers probably have higher levels of temporary and low-level vocal fatigue than the "normal" non-professional singing boy, but, on the other hand, the choristers have shown lower levels of severe dysphonia. The second, by Dejonckere et al (Dejonckere et al., 1996), showed a significantly better periodicity of the fundamental frequency in the young singers, due to better mechanical characteristics of vocal fold vibration.

This data supports what speech therapists empirically observe in their clinical practice: the child's vocal education is defensive against dysfunctional laryngeal pathologies, inducing in the child a greater awareness of their own use of the voice. Hence the great responsibility of singing teachers and choir directors who must educate children to correct vocal emission.

Voice training in children and adolescent

The first objective of musical education - nowadays shared between singing teachers, speech therapists and phoniatricians - is to introduce the child to singing through the discovery of the voice as a means of expression, without inducing tension or effort in the vocal production apparatus. In preschool age natural singing must be privileged, as it represents the discovery of the voice as a means of expression trough perceptive sensorial training in rhythm, vibration, variations in intensity and frequency, the sensation of light and heavy, smooth or rough. Creative games or other playful activities can also be useful.

Later, in the school age, a more formal study of singing can be undertaken including management of vocal registers, recognition of vocal changes towards falsetto, enhancing vocal agility and stability, through exercises at different speeds with tonal variation. In order to prevent vocal abuse, it is important to teach the young singer to manage the respiratory support, to avoid overuse of intensity and of singing outside the adequate vocal range.

The choir promotes the socialization and well-being of the child, but must be directed by a careful teacher who is aware of the risks that singing in a choir entails:

- the loudness produced by the choir reduces auditory feedback, which can lead the chorister to increase the phonatory volume, causing laryngeal hyperfunction,
- the chorister may have to face a repertoire that is not suited to his vocal range, resulting in chronic vocal fatigue.

Anyway, in the first years of singing, the choice of repertoire must include a comfortable texture, an easy melodic line without excessively difficult intervals, a comfortable phrase from the point of view of the breath and the absence of extreme dynamics.

The singing activity may progressively lead to an improvement in the vocal performance, whereas it may give rise to voice disorders requiring treatment in another child. When the strain is too great for the vocal apparatus, increased singing activity can cause, in particular, functional dysphonia and dysodia (Fuchs et al., 2008). At the first signs of vocal fatigue (Fig1), it is important to refer the child to an ENT or phoniatric evaluation and, if necessary, speech therapy.

Changes in male voice at puberty

The vocal changes that males undergo during puberty are inconsistent, as they are unstable and unpredictable, and result in difficulties for both the singer and choral director. Mutation is a very delicate phase in the development of the voice, highly at risk of functional laryngeal pathologies (Hacki et al., 1999). These include an increase in breathing capacity and an increase in neck length and width, which leads to a relative descent of the larynx, and subsequent enlargement of the vocal tract and resonatory system. Growth of the paranasal sinuses and nasal turbinates, with atrophy of the tonsils and the adenoids, also affects vocal quality (Harries et al., 1997).

As regards the changes in the voice, in males, more or less suddenly, there is a reduction in the average F0 of 12 semitones in males, compared to the 3-4 semitones that occur in females. In particular (Hacki et al., 1999):

- *pre-mutation* (10 -12 years): worsening of F0 by a semitone in both sexes (first sign of mutation around 10 years), with still good performance of the white voice due to the expansion of resonators, but gradual appearance of phonatory instability and breathy voice during singing;
- *voice mutation* (13-16 years): reduction of frequency range and vocal instability with frequent vocal breaks in falsetto or sudden worsening of the fundamental;
- *post-mutation*: progressive stabilization of the conversational F0, with a voice of a darker tone, of greater intensity, well resonant, with the absence of the noise component.

During the voice change in puberty, a careful management of the singer's voice is required from the singing teacher, according to progressive voice mutation. In the musical field John Marion Cooksey (Fig. 2) has established a six-stage pattern of voice development in puberty based on vocal range, tessitura and average F0:

- **Stage 0**: *Unchanged*: Range 220 - 698 Hz [La 3 – Fa 5], Tessitura 277,18 - 493,88 Hz [Do#4-La#4], Average SF0 range 220 - 260Hz [La 3 - Do 4]
- **Stage 1**: *Mid-voice1*: Range 208 - 523 Hz [Sol #3 – Do5], Tessitura 247-392 Hz [SI 3 – Sol 4] Average SF0 range 220 - 247Hz [La 3 – Si 3]
- **Stage 2** : *Mid-Voice II* : Range 175 - 392 Hz [Fa3- Sol4 o La4] Tessitura 208-349 Hz
  [Sol #3 – Fa4] Average SF0 range 196 - 233Hz [Sol 3 – La 3]
- **Stage 3**: *Mid-Voice II A*: Range 147-370 Hz [Re3- Fa#4], Tessitura 185-262 Hz [Fa#3 – Do4] Average SF0 range 175 – 185 Hz [Fa3 – Fa#3]
- **Stage 4**: *New Voice-Baritone*: Range 123 - 311 Hz [Si 2 – Re#4], Tessitura 155 – 246 Hz [Re#3-Si3] Average SF0 range 131 - 165Hz [Do 3 – Mi 3]
- **Stage 5**: *Emerging Adult Voice*: Range 98 – 293,66 Hz [Sol 2– Re4], Tessitura 123-416 Hz [SI 2 – Re4] - Average SF0 range 110 - 139Hz [La 2 – D0#3]

It is interesting to note that the most important changes in the voice occur in males between Tanner's stages 3 and 4, that is to say that the worsening of the fundamental occurs in an advanced phase of puberty (Beger et a., 2018).

Although this delicate phase of the young singer's management is entrusted to the singing teacher, at the first signs of vocal fatigue a careful phoniatric evaluation must be requested, to both objectively evaluate, in laryngoscopy, the morphological changes of the larynx, and highlight possible initial functional alterations.

Conclusion

Singing represents an extraordinary opportunity for the affective, emotional and cognitive development of children, promoting their socialization. However, the children's delicate phonatory physiology must be respected. They certainly must avoid singing an adult repertoire, unsuitable for them, and they shouldn't use the power of their voice as a means to assert themselves in a group or express feelings of anger or frustration. They will have to be guided to the discovery of all the emotions that singing can offer in a condition of serenity, avoiding any excessive effort. In this way singing will be a great opportunity for them not only to grow serenely and joyfully, but also to receive an unconscious training in the correct use of the voice, avoiding pathologies caused by vocal strain.

References

Berger T, Peschel T, Vogel M, Pietzner D, Poulain T, Jurkutat A, Meuret S, Engel C, Kiess W, Fuchs M. Speaking Voice in Children and Adolescents: Normative Data and Associations with

BMI, Tanner Stage, and Singing Activity. J Voice.2019;33:580.e21-580.e30. doi: 10.1016/j.jvoice.2018.01.006.

Cooper RP, Aslin RN. Developmental differences in infant attention to the spectral properties of infant-directed speech. Child Dev. 1994;65:1663-77. doi: 10.1111/j.1467-8624.1994.tb00841.x.

Dejonckere PH, Wieneke GH, Bloemenkamp D, Lebacq J. Fo-perturbation and Fo/loudness dynamics in voices of normal children, with and without education in singing. Int J Pediatr Otorhinolaryngol. 1996;35(2):107-15. doi: 10.1016/0165-5876(95)01291-5.

Fuchs M, Meuret S, Geister D, Pfohl W, Thiel S, Dietz A, Gelbrich G. Empirical criteria for establishing a classification of singing activity in children and adolescents. J Voice. 2008 Nov;22(6):649-57. doi:10.1016/j.jvoice.2007.02.004.

Grebosz-Haring K, Thun-Hohenstein L. Psychobiological responses to choir singing and creative arts activities in children and adolescents with mental disorders: results of a pilot study. Neuropsychiatr. 2024;38:145-155.

Hacki T, Heitmüller S. Development of the child's voice: premutation, mutation. Int J Pediatr Otorhinolaryngol. 1999;5;49:S141-4. doi:10.1016/s0165-876(99)00150-0.

Harries ML, Walker JM, Williams DM, Hawkins S, Hughes IA. Changes in the male voice at puberty. Arch Dis Child. 1997;77:445-7. doi:10.1136/adc.77.5.445.

Lee DR, Weinrich B, Zacharias S, LeBorgne W, Beckmeyer J, Eanes C, Tabangin ME, de Alarcon A. Endoscopic Findings in Male Prepubertal Choir Singers. Laryngoscope. 2021;131:592-597. doi: 10.1002/lary.28786.

Martins RH, Hidalgo Ribeiro CB, Fernandes de Mello BM, Branco A, Tavares EL. Dysphonia in children. J Voice. 2012;26:674.e17-20. doi:10.1016/j.jvoice.2012.03.004.

Panksepp J, Bernatzky G. Emotional sounds and the brain: the neuro-affective foundations of musical appreciation. Behav Processes. 2002 Nov;60(2):133-155. doi: 10.1016/s0376-6357(02)00080-3.

Papageorgi I, Saunders J, Himonides E, Welch GF. Singing and Social Identity in Young Children. Front Psychol. 2022,2;13:823229. doi:10.3389/fpsyg.2022.823229.

Rogers DJ, Setlur J, Raol N, Maurer R, Hartnick CJ. Evaluation of true vocal fold growth as a function of age. Otolaryngol Head Neck Surg, 2014;151:681-6. doi: 10.1177/0194599814547489.

Sapienza CM, Ruddy BH, Baker S. Laryngeal structure and function in the pediatric larynx: clinical applications. Lang Speech Hear Serv Sch. 2004;35:299-307. doi: 10.1044/0161-1461(2004/029).

Speranza L, Pulcrano S, Perrone-Capano C, di Porzio U, Volpicelli F. Music affects functional brain connectivity and is effective in the treatment of neurological disorders. Rev Neurosci. 2022 Mar 24;33(7):789-801. doi:10.1515/revneuro-2021-0135.

Titze IR. Theoretical analysis of maximum flow declination rate versus maximum area declination rate in phonation. J Speech Lang Hear Res. 2006;49:439-47. doi: 10.1044/1092-4388(2006/034)

Williams J, Welch G, Howard DM. An exploratory baseline study of boy chorister vocal behaviour and development in an intensive professional context. Logoped Phoniatr Vocol. 2005;30(3-4):158-62. doi: 10.1080/14015430500262095.

Woodward SC. Fetal, Neonatal and Early Infant Experiences of Maternal Singing. In The Oxford Handbook of Singing. Welch F, Howard D, Nix J editors. Oxford Handbooks Online, 2017.

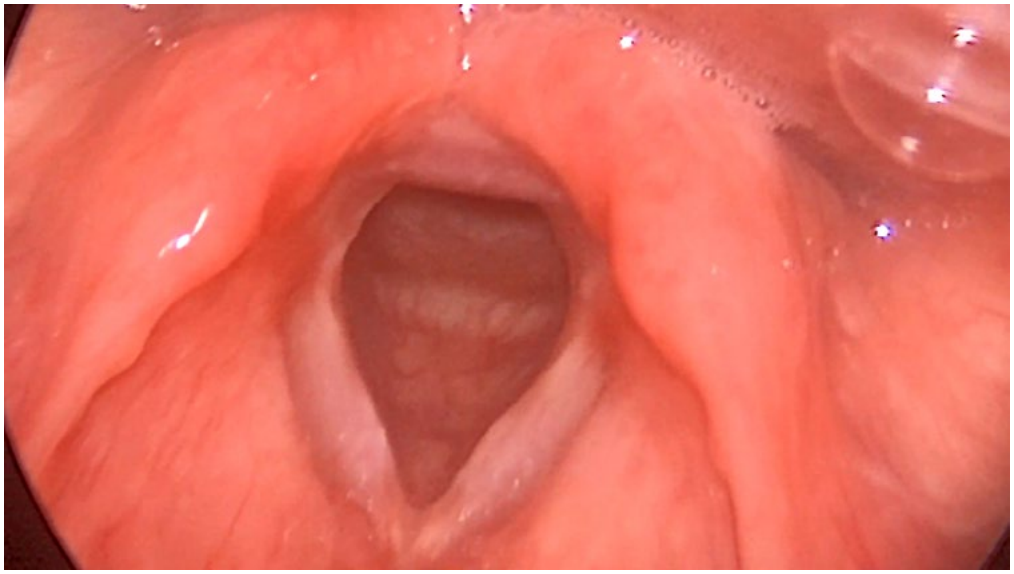

Figure 1: Initial nodular point swelling in a prepubescent singer.

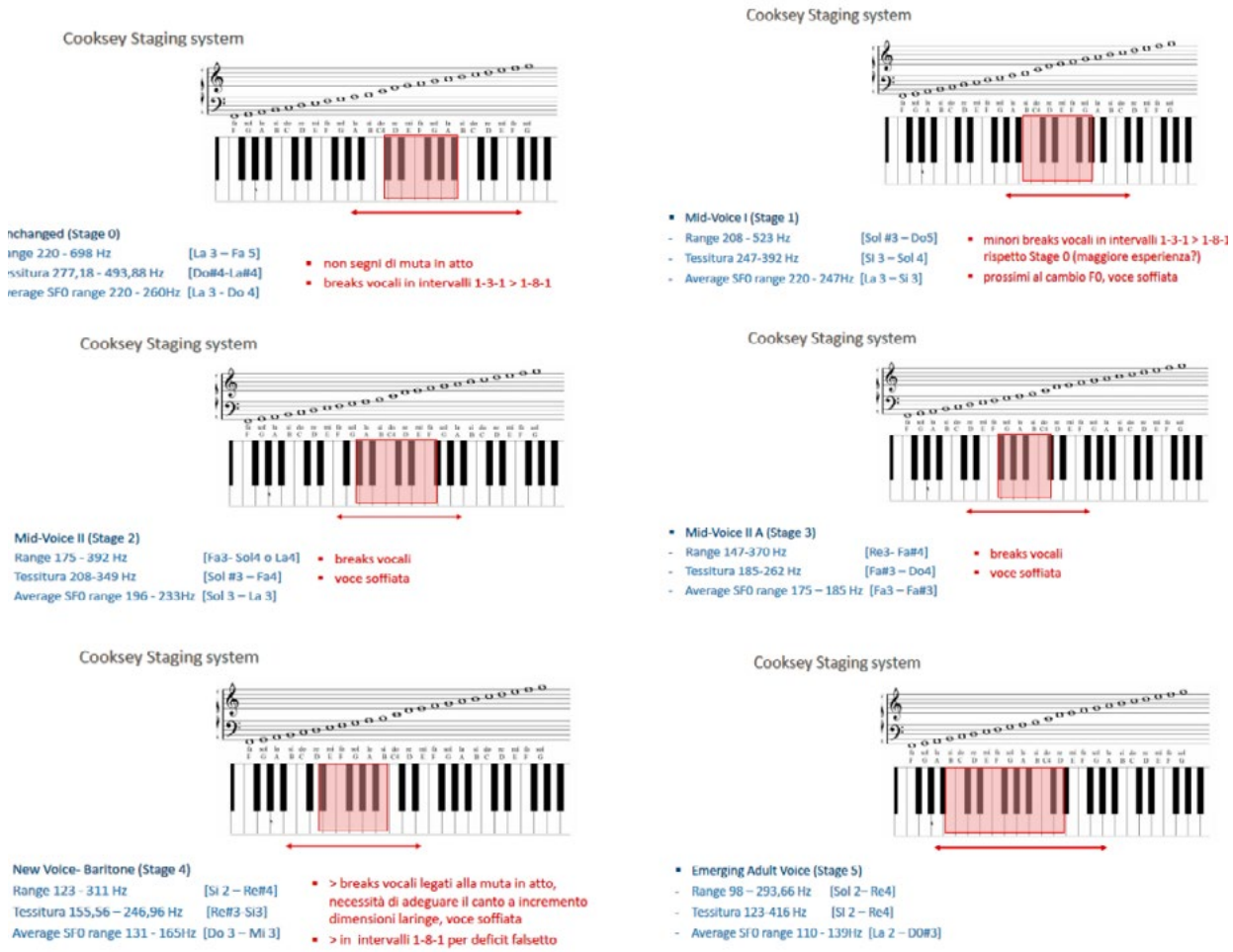

Figure 2: John Marion Cooksey six-stage pattern of voice development in puberty