Neurophysiological implications of rhythmic aptitude development

A conversation with Giuliano Avanzini

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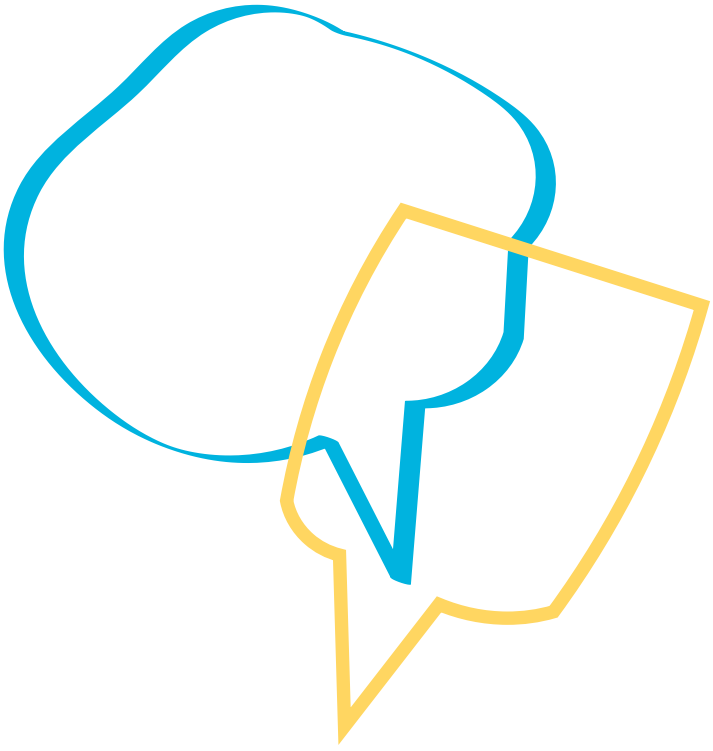

This conversation with Giuliano Avanzini, head physician of neurology at the Carlo Besta Institute in Milan, highlights the positive synergies emerging from an infant's early exposure to music. This may occur as soon as the prenatal period and in any case at a preschool age, and involves the neuro-functional development of various abilities: motor, linguistic and relational.

Considering the huge amount of interest shown towards the phenomenon of rhythmic-motor entrainment generated by listening to metrically organised music, our intention here is to bring out the neuro-scientific data underlying this complex process. Further attention will go to its clinical and therapeutic implications in motor recovery for people suffering from Parkinson's disease, or dyslexic or stuttering children, and more generally for the strong drive towards socialisation produced by the act of rhythmically attuning to the music to which one listens.

Children who listen to rhythms and songs without words as of their first days of life, for example during the musical sessions inspired by Edwin Gordon's Music Learning Theory (MLT), and who are led along an informal path of acquiring the rhythmic and tonal competence inherent in musical syntax, are unfailingly moved by the music they listen to. They are also brought to interact with it in various ways: from simply orienting their heads and eyes towards the voice singing for them, to moving their limbs and torso in synchrony with the perceived pulsation; from monosyllabic rhythmic babbling, to vocally reproducing the rhythmic patterns proposed by the teacher; or again, in a metric type of rhythmic-motor

coordination, i.e. one that is expressed on more than one level of a temporal structure at the same time.

I.D – Dear Professor, can we define these manifestations as rhythmic-motor entrainment in musical listening? What is the phenomenon of entrainment in music?

G.A.– The origin of this term, now widely used in the Anglo-Saxon literature, lies in the French word *entraîner* (to pull or drag along, physically or otherwise). It is used to indicate music's particular ability to get listeners involved in a "participative" manner. One fundamental component of this involvement produced by music has to do with to its temporal dimensions and in particular its rhythmic articulation. The "pull" exerted by a highly rhythmic type of music is a common experience, obvious even to an external observer by way of the sometimes irresistible tendency for listeners to accompany it with rhythmic bodily movements.

Interesting work has been done by the Montreal group[113] and the one led by Chapin[114], who have irrefutably demonstrated that motor areas of the brain participate in the processes of rhythmic perception, even without bodily movements accompanying the music being carried out by the subject. This is an important observation for the neurosciences, because it confutes the traditional separation between the anatomic and functional organisation governing perception and the one responsible for producing movement. The involvement of motor centres in the perception of rhythm is a decisive contribution to defining musical listening as active listening.

I.D.– Listening, perception and movement. Three cornerstones of development. Is there a rhythm that also marks the neural mechanisms underlying the perception of pulsations and synchronisation?

G.A.– Since musical rhythm can be defined in terms of measurable sizes, primarily the duration of the rhythmic units and the frequency of the condensation of energy that defines accents, a great deal of effort has been dedicated to identifying correlated and measurable neurophysiologic elements. In particular, attempts have been made to grasp the relation between musical rhythm and neural rhythms. This is a fascinating field of research but not without its risks, in that the sophisticated analytical methods that neurophysiology offers us call for all of the variables lying between the signal's recording and its correct interpretation to be accurately controlled. In this specific case, the digital elaboration we use to extract the rhythmic content of the signal could introduce constraints that alter its rhythmic components in a non-uniform way, creating distortions that make the results unreliable. Excuse me for this technical digression, but I believe one must underline the risk of basing one's judgement of dependability on technological aspects that contribute more to the aesthetical presentation of the data than they do to its scientific reliability. As regards neurophysiologic elements correlated to musical rhythms, much interest has been aroused by the approach based on the "steady-state evoked potential" (SSEP) or "frequency tagging" technique[115], which takes advantage of the ability that periodically repeated stimuli have to generate periodic modifications in the amplitude of the electricity generated by the brain and recorded on the surface of the cranium (electroencephalogram: EEG). With this technique,

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[113] CHEN JL. ET AL., "Listening to musical rhythms recruits motor region of the brain", *Cerbral Cortex,* 2008.

[114] CHAPIN HL. ET AL.,"Neural responses to complex auditory rhythms: the role of attending", *Frontiers in Psychology,* 2010.

[115] NOZADARAN S., "Exploring how musical rhythm entrains to brain activity with electroencephalogram frequency-tagging" 2014 *Philos. Trans. R. Soc. Lond. B. Biol. Sci.* 369: 20130393, 2014.

Laura Cirelli and her collaborators[116] have demonstrated that rhythmic EEG responses, correlated to a pulsation and a meter, already appear in seven-month old babies and that, thanks to its sensitivity, SSEP can be used in longitudinal studies of the development of the competences involved. It seems to me that this data well corresponds to the working experience gained by yourself and all those who follow the principles of MLT.

I.D.- Yes, I've read Cirelli's study, it seems that she proposes listening to sequences of pulsations with various articulations and without binary, ternary or other subdivisions, but that can be interpreted that way by the children listening. At the same time, she records the peaks of attention with an EEG and deduces a metric interpretation, as though the sequences of pulsations were given a binary or ternary rhythm by the listeners (children). It brings to mind our inborn tendency to metrically elaborate isochronous sequences of pulsations, for example the tick-tock of an alarm clock, a metronome or even a heartbeat, automatically giving them a form of accentuation. Is that correct?

G.A. – Yes, yes, yes, I am absolutely convinced that whether an acoustic event is defined as music or not does not depend on its intrinsic characteristics but on the listener's perception, and that the identification of a metric articulation is the fundamental passage that can give value as music also to sounds produced with no musical intention, such as the regular, rhythmic noise produced by the wheels of a train. Obviously, some characteristics of the acoustic stimulus can make the perception of a sound's musical quality more immediate and easily shared, meaning that while few people would have any doubts as to the musicality of a Haydn symphony, many more would have problems in defining as music sounds that have a low degree of seduction, or entrainment, such as the screech of a tram's wheels as it goes around a curve (or even *Ionization* by Edgard Varèse, if it comes to that).

I.D. – Certainly, it would be interesting to see whether any differences arise in the motor effect generated by a non-metrically organised piece of music, bearing solely on certain less usual aspects of music.

Do you think that the higher possibility of synchronising with a pulsation demonstrated when listening to metrical sequences rather than simple isochronous pulsations, and an even higher one when the metrical sequence is part of a musical context rather than a simple tapping, is part of the phenomenon of entrainment? And could the fact that a more complex rhythmic stimulus produces a greater effect perhaps mean that more than one functional domain is perceptibly involved?

G.A.- I think you can answer the first question better than me, but yes: I believe that a musical context favours entrainment both because rhythmic articulation is a fundamental element, even if not the only one, of entrainment, and because the perception of rhythm and metre is influenced by non-temporal variables (pitch, intensity, melodic and harmonic structure).

Regarding you second question, I'm not sure I understand which domains you are referring to.

I.D – I'm referring to the involvement of all the musical parameters you have just mentioned, and so the possibility of receiving a much higher quantity of information and stimulation, which activates areas of the brain that are responsible for other functions as well, involving language, emotions or memory.

G.A.- Having said that the neurosciences are currently moving towards correcting the idea that these functions take place in a limited topographical location of the brain,

[116] CIRELLI L. K., SPINELLI C., NOZARADAN S., TRAINOR L. J., "Measuring Neural Entrainment to Beat and Meter in Infants: Effects of Music Background", *Frontiers in Neurosciences,* 24 May 2016.

suggesting rather an anatomic-functional organisation that works through neural networks, understood as sets of interconnected areas, one must say that the neural networks involved in perceiving and producing music include areas implied in the control of movement, language, memory and other non-auditory functions. It is therefore reasonable to assume that practices that strengthen musical abilities can be beneficial for various functions, that depend on the activity of the same neural systems.

I.D. – I'm very interested in the study by Carolyn Drake and her collaborators[117] of how listeners' ability to discern various temporal levels while listening to music changes with their growth, and how temporal perception slows down with age, with other changes concerning the way of using time and decoding the various metric levels. Drake speaks of a specific temporal referent period for each individual, which is independent of the degree of rhythmicity found in external sounds, and in a certain sense reflects a person's generic subjective sense of time. This may coincide with a particular temporal level within a musical context, defined as the referent level because it is correlated to a regular temporal event that is actually present in the musical stimulus, which we might call *tactus*. Attunement with an external musical stimulus comes about when this subjective time adapts to, is brought in line with or synchronised with one of the metric levels marked by the tempo. Darke relates the possibility of synchronising oneself with pulsations that are increasingly distant form one another while listening, to maturity as measured by an adult's level of attention compared to that of a child. I believe, however, that an important role is also played by growth, acquiring an upright posture and decreasing the distance between our footsteps when shifting our weight, thus allowing us to move not only on the lower levels of a metric hierarchy, but also on higher ones, those in which the pulsations are farther apart.

What do you think of this? In your opinion, does a relation exist, for example, between the length of children's limbs in their first two years of life and their ability to coordinate themselves with the music the hear, inevitably oriented towards rhythmic frequencies with a higher number of pulsations per second? Is it useful to consider the fact that the oscillation of a limb has a oscillatory frequency amplitude that is inversely proportional to its length?

G.A.- The length of children's limbs is definitely correlated to their walking rhythm. Most likely, more information has been published about this than I am aware of. Some recent data has come from a population of Chinese children in three age groups, in which the frequency of their steps is inversely related to the length of their limbs[118]. This kind of study risks losing its validity, however, because in addition to the length of their limbs other variables may interfere, having to do with the child's maturational development. What I mean is that a child whose limbs are longer than another's may be in a more advanced phase of development compared to another with shorter limbs, and thus there may be other maturational factors that explain their preference for a different gait. As regards the first part of your question, I agree that a more powerful stimulus engages multiple levels of attention and perception, and also with the idea that a complex stimulus can easily make its influence felt in not strictly musical areas.

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[117] DRAKE C. ET AL., "The development of rhythmic attending in auditory sequences: attunement, referent period, focal attending", *Cognition* 77, 2000.

[118] Wu M ET AL., "Analysis and Classification of Stride Patterns Associated with Children Development Using Gait Signal Dynamics Parameters and Ensemble Learning Algorithms", *Biomed Res Int,* 2016.

I.D.- I wonder if our internal rhythms of attention, as defined by Jones and Boltz[119], can be referred to the generic subjective time of a person, which can be deduced for example by asking them to spontaneously beat a tempo without any external acoustic signal[120].

What is meant by internal rhythms of attention? Could it be that ingrained rhythms exist that are favoured with respect to others, and thus are able to be expressed precociously in a movement synchronised with a given rhythmic frequency present in the musical context of a piece one is listening to, rather than others?

G.A.- Rhythms that are more favoured than others certainly exist, as is demonstrated by the preference for metres based on simple temporal relations (2:1, 3:1, 3:2) and for rhythms and agogics that create certain temporal intervals (300-800 ms[121]). I am not sure however that one can speak of an inborn predisposition, given that many observations have underlined the importance of the environment in defining preferences that can be noticed as of the first months of an infant's life. The surrounding sound environment may even influence an infant during their intrauterine life, and in this case one could still speak of innate (or, perhaps better yet, connate) rhythmic preferences, but without necessarily implying genetic factors. Concerning innate rhythms, attempts have been made to correlate rhythmic preferences with a few biological rhythms, for example concerning the heartbeat, but in my opinion the results are not very convincing.

I.D.– It seems to me, indeed, that gastric sounds, breathing rhythms and the gait have more of an influence than the heart. In any case, what is involved is rhythm and movement.

If we reflect on how important movement is for a child's cognitive, relational and empathic development, as a primary instrument for acting in the world surrounding them, and how this is stimulated by music and its rhythmic aspects in particular, then observing and motor-imitating adults moving in time to music, listening, singing, dancing and making music together, should give an enormous stimulation to this process. All of this turns into a window through which to observe any possible shortcomings or lacks in a child's motor repertory. Do you agree?

G.A.– No doubt, observation during the musical sessions would enrich evaluation, as is the case with many of the aspects were are discussing. It would however be necessary to develop a multidisciplinary and integrated approach, which can only be achieved in the presence of a strong motivation to take the risk of contaminating one's own knowledge with that developed by those who cultivate different disciplines. Exactly the opposite of what would seem to be the dominant tendency: avoiding interactions that might jeopardise certainties and protections that wind up taking the form of separating walls.

I.D.– It is well known that synchronisation with a visual metronome is worse than with an acoustic one, even though a pulsation can be deduced from visual metric sequences as well, for example by using flashes of light. In a child's process of rhythmic-motor synchronisation, how influential is observing an adult moving in time to music rather than simply listening to the same music?

G.A.– I would be careful about equating different visual stimuli (an adult moving in time to music, and a visual metronome), due to the new developments that have

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119 JONES M.R., & BOLTZ M., "Dynamic attending and responses to time", *Psychological Review*, 96 (3), 1989.

120 Cfr. DRAKE ET AL., op. cit.

121 FRAISSE P., "Rhythm and tempo. In D. Deutsch, *The psychology of music,* New York: Academic Press, 1982.

opened up thanks to the discovery of mirror neurons[122], motor cells in the brain that fire not only while a given movement is being carried out, but also when seeing someone of the same species performing that same movement. We know little as yet about the development of mirror neurons following birth, but there are good reasons to believe that the mirror system is developed fairly early. One recent work demonstrates, in any case, that an infant who is used to seeing video recordings of adults dancing is able to perceive audio-visual synchrony between eight and twelve months of age, and that this ability only comes to light with films that contain a synchronised form of both types of information, visual and audio[123].

I.D.– I am highly curious about the synergy between sight and listening, and how vision comes together in a reciprocal enhancement during certain situations while instead causing a disturbance in others. Often musicians listen or play with their eyes closed, or else concentrated on a point on the horizon which they are actually not observing but that only functions as a catalyser for their attention, and any incursion into their field of sight disturbs the listening experience or the performance. Seeing an architectural rhythm created by a series of pillars along a wall gives us a sense of order, but does not involve us in a visual flow, as is the case with musical rhythm.

We might recall the gestures of a conductor and how the orchestral musicians respond: here, the two realms are correlated to the highest degree. How much does the influence of the visual domain count, and how important is audiation? That is, already having in mind the music I'm about to play and therefore referring to it the motor and gestural indications of the director?

G.A.– I think that the fundamental element is audiation, understood as an internal representation of a piece of music and, in our case, of its rhythmic structure. Nonetheless, I believe that this representation is subjective and therefore differs between one musician and another, and even for a single musician from one moment to the next. This doesn't raise any problems for a solo interpreter, but inevitably does for ensemble music. I believe that the role of the conductor is precisely that of harmonising the "individual audiations" within a "group audiation".

I hope you realise the risk I am taking by venturing into a field in which I am not professionally prepared.

To stick to aspects that are more acoustic than musical, I would say that events that are repeated according to a physically defined rhythm can be concordant but not necessarily in phase. For certain purposes, including that of making music together, a "synchronising" function is thus required that in this case would be covered by the director. Obviously, the layman would tend to believe that the conductor/demiurge has the absolute power of attuning the musicians; I wonder, however, if in some subtle way, that is difficult to define, there might not also be an influence coming back from the musicians to the director. (Who knows if it's my democratic leanings that are showing through here?!)

I.D.– Could you explain to us how and why music's higher power of entrainment becomes beneficial with respect to language? For example, in curing dyslexia.

G.A.– The term dyslexia refers to a reading impediment involving a difficulty in decoding written texts that is not due to sensory or intellectual shortcomings. Dyslexia is

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122 RIZZOLATI G. ET AL., "Neurophisiological mechanism underlying the understanding and imitation of action", *Nat Rev Neurosci*, 2, 2001.

123 HANNON E.E. ET AL., "Babies know bad dancing when they see it:older but not younger infants discriminate between synchronous and asynchronous audiovisual musical displays", *Journal of Experimental Child Psychology*, 159, 2017.

part of the group of specific learning disabilities (SLD) that concern the ability to read, write and calculate correctly and fluently, and that are brought together by the fact that they appear in the early period of education The core of dyslexia as a disability is phonological, and has to do with linguistic prosody. It is therefore reasonable to expect dyslexia to be constantly associated with difficulties in tasks that require action and perception to be organised over time, such as recognising rhythms and synchronisation. On this basis, the effectiveness of musical training and exercise programs in cases of dyslexia has been studied. Some particularly important studies done by Flaugnacco and his collaborators[124] have used, in addition to neuropsychological language tests, other tests specifically developed with psychoacoustic materials. The results demonstrate that musical exercise significantly improves reading and phonological abilities, even in highly complex cases, which opens up interesting prospective for curing dyslexia.

I.D.– Turning to other images, we might say that the reason why this happens lies in the fact that music is a means to make "concrete" a time that does not exist in itself, and thus offers the dyslexic a structure to lean on that elsewhere would be difficult to find. Rhythm is thus an organising and ordering element, but also one that is in evolution, that flows and allows for a process of transformation that takes concrete form over time, and by way of time, as should be the case in reading and, for stutterers, with speech.

G.A.– I couldn't come up with a better image!

[124] FLAUGNACCO E. ET AL., "Music Training Increases Phonological Awareness and Reading Skills in Developmental Dyslexia: A Randomized Control Trial ", PLoS ONE 10, 2015.