Rhythmic brain and education

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Executive Summary

- The rhythmic activity of the brain can align with the rhythmic occurrence of external stimuli, for instance with the occurrence of the syllables in utterances.
- This alignment process is called neural entrainment and can be measured with safe techniques such as the electroencephalogram.
- The precision and strength of the neural entrainment to speech and music associate with higher linguistic abilities.
- Interventions mainly comprising the practice of playing a musical instrument are associated with benefits on linguistic, executive, and attentional skills
- Rhythmic abilities are ubiquitous in the world and can be exploited to support preschool and school education in a safe, ecological and non-expensive way.

Introduction

Over the past decades, several studies have revealed the amazing capacities of young infants as learners[1]. Most studies described what and when infants learn. Only in the last two decades the research focused on investigating the mechanisms explaining "how" young children learn.

One of those mechanisms would exploit the rhythmic properties of the brain and how they align with the rhythmic properties of the environmental stimuli. Many neuroscientists call this process "neural entrainment". Neural entrainment is the process by which the rhythmic activity of the brain aligns with the rhythmic properties of the incoming stimuli over time (Figure 1). What would be important for neural entrainment is how strong and precise is the alignment. Although all biological activities of living beings are rhythmic, the neural entrainments most explored have been the neural entrainment to speech and the neural entrainment to music.

Neural entrainment for speech

The recent advances in neuroscience's methods have allowed quantifying how well the brain and speech synchronize to each other in adults[2,3], children[4,5], and infants[6].

Speech is an oscillatory signal, composed of sequences of speech sounds, such as syllables and words, that occur recurrently over time. These speech sounds take place at regular rhythms. For instance, when we speak normally, we utter ~4 syllables every second, when we speak to young children we speak slower producing ~2 syllables every second, and when we speak fast we produce ~6 or more syllables per second. In any case, human adults are able to understand similar information. Neural entrainment would be a mechanism that may partially allow this ability.

The brain activity is also oscillatory with a wide range of variations, from very slow (one oscillation every several seconds) to very fast (above 50 oscillation every second).

Thus, speech and brain activity can align their oscillations at certain rhythms. For instance, in normal speech adults utter ~4 syllables every second. The precision and strength of the alignment between the speech signal at ~4 syllables per second and the brain oscillations taking place at 4 oscillations per second predict speech intelligibility[7] and word comprehension[8] in adults. Moreover, the neural entrainment to speech prosody associates with higher attention to the spoken stimuli[9], higher speech intelligibility in noisy environments[10], and, when listening to two speakers simultaneously, associate with selective attention to the attended speaker[11,4].

Although the neural entrainment to syllable has been observed in 8-month-olds infants exposed to known continuous speech and associates with higher performance discovering words embedded in fluent speech6, the processing of fast speech is particularly challenging for children[12], indicating that the developing brain has difficulty aligning with certain speech stimuli.

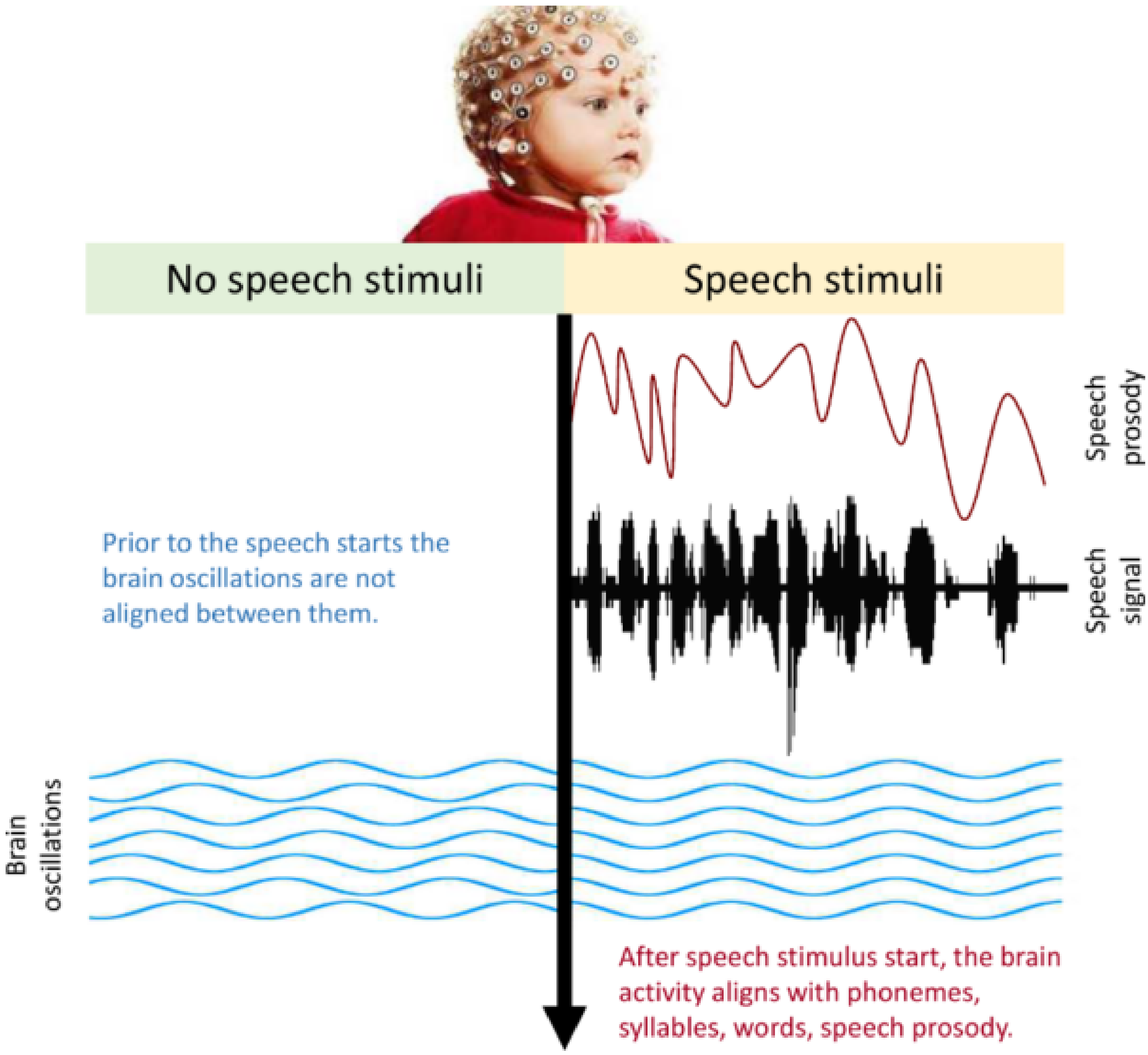

Figure 1. This figure represents a cartoon about neural entrainment to speech during infancy. In silence, the brain oscillations across the brain would not be aligned but mainly randomly changing. When the speech signal starts, the infant brain would perceive would align to each other while the speech signal develops. The alignment of the brain oscillations takes place simultaneously at different rates. For instance, in English when speaking normally, the brain activity entrains with the occurrence of the syllables, which is about 4 to 6 syllables every second, at the same time that it entrains to words, which take place at 2 to 4 words per second. Moreover, the brain activity entrains with the prosody of the utterances, somehow mimicking the variations in the intensity of the utterances. The intensity and precision of how the brain aligns its activity with the spoken stimuli relate to the levels of speech comprehension, attention, and speech intelligibility.

How would the neural entrainment to speech works?

Some visual studies in adults have shown that visual events that occur 'out of phase' do not reach conscious awarenes[13], and consequently are not explicitly learned.

The neural entrainment to speech would allow us to "select" the stimuli we perceive from an environment, which almost always contains many sounds. For instance, in the street speech sounds are simultaneously presented with the sounds of cars, closing doors, animals' vocalizations, and many others. However, humans succeed to process speech even in noisy environments.

More generally, neural entrainment would also benefit predictive thinking. Indeed, brain oscillations are conceived as anticipatory mechanisms to make predictions about the ongoing stimuli. Anticipating near-future events is fundamental for adaptive behavior, facilitating the processing of predictable stimuli over the non-predictable ones. Indeed, adults usually anticipate the end of a sentence of the interlocutor during a conversation, which is also perceived as a sign that we are reading the other mind.

Thus, speech and communication learning would benefit from the neural entrainment to speech for both, stimuli selection and anticipatory thinking.

Recent studies have shown that neural entrainment to speech is not a consequence of speech perception but rather they are causally related. A good example is the so-called "cocktail-party effect". In a cocktail party, we are usually in a noisy environment with many people speaking simultaneously. However, if we hear something that calls our attention, such as our own name, we are able to selectively attend to this particular source of speech, even when we do not have to look toward the source. In adults, the studies show that the higher intensity of the neural entrainment toward the attended speech source positively associates with higher speech intelligibility[14], indicating that the brain can voluntary align to the speech signal that attracts our attentional resources, even when the environment is noisy.

Similarly, our studies found that neural entrainment is controlled by what we are perceiving. When adults are exposed to unknown continuous speech streams composed by tri-syllables, the adult brain initially increases the neural entrainment to syllables, however, after discovering the tri-syllabic words, the neural entrainment to syllables decreases while the neural entrainment to words increases[5]. This effect is also observed in 8-month-olds infants[6].

Together the brain results indicate the study of the neural entrainment to speech is an efficient method to assess speech processing and probably promote speech learning.

What the NE may tell us about language acquisition?

Neural entrainment to speech reveals the natural interest that humans have for speech over other auditory stimuli. Thus, during early development, a more precise alignment of the infant brain activity with speech sounds would help the infant's brain to attune with the speech sounds of their native language.

Humans prefer listening to speech over many other types of sounds from birth. For example, neonates selectively attend to normal speech over speech subtly distorted[15,16], as well as over white noise[17]. This preference is reduced in infants who lately develop autistic-like behaviors[18].

Moreover, a recent study has shown that 8-month-olds develop higher neural entrainment to speech prosody (or melody) when they listen to infant-directed than to adult-directed speech[19]. Infant-directed speech is a style of speaking that adults use when addressing young children. Infant-directed speech is mainly characterized by greater variations in the highness and intensity of the voice, and slower speaking[20]. It is conceived as a powerful social signal that attracts infant attention and makes infants notice that the spoken information is addressed to them[21]. An additional important point is that the processing of the speech prosody contributes to recognizing the identity of the speaker, distinguishing the familiar and foreign persons between them.

An additional benefit of precise neural entrainment to speech during language acquisition is that it facilitates the learning of the native phonemes repertory, which are the minimal sounds that allow distinguishing words in the native language, such as /r/ and /l/ which differentiate the words /rot/ and /lot/ in English, but they do not distinguish any words in Japanese been perceived as equal.

Neural entrainment and linguistic skills

The neural entrainment to speech may play a crucial role in the learning of word-object and word-action associations. In natural environments, children are taught in non-transparent conditions. For instance, we tell them utterances like "look this is a dog", while the dog is jumping in a garden surrounded by toys, plants, and other referents. A more precise neural entrainment to speech would facilitate the memory of the correct association.

Word-object association learning is a milestone in language acquisition and a central ability for social communication[22]. Word-object association learning is observed in infants as young as 8 months of age[23], and notably, it can succeed even when auditory and visual stimuli are simultaneously presented in continuous audiovisual streams[24]. A crucial factor in this task is the synchronic presentation of spoken words and images. For instance, even 4-month-olds become fussy and distressed when watching a "talking head" where the visual speech information is "out of sync" with the auditory information[25]. Mothers of 6-month-olds instinctively know that fact and, when teaching the name of an object to their infants, they try to synchronize with the infant's attention. The studies show that the greatest synchrony between mother and child, the highest accuracy in word-object learning the child reaches[26,27]. Interestingly, this behavioral synchrony is poor in autistic children with linguistic difficulties[28].

Thus, at least the neural entrainment to syllables and to speech prosody seems to be a promising brain tool to evaluate linguistic abilities in young children, and has inspired rhythm-based interventions.

Neural entrainment to music and language capacities

Several rhythmic interventions in children with language difficulties have shown improvements in linguistic abilities. For instance, the drum playing practice associates with improvement in phonological awareness and reading[29]. At least partially, rhythmic interventions would work because they would train the ability of the brain to align with the ongoing stimuli, improve the attention and the awareness of the synchronic coordination between perception and action.

One of the most powerful signals to entrain the brain would be music. Musical practice involves the training of precise neural entrainment not only to the timing of tones but also to the emotions that the music conveys. Additionally, the musical practice entrains the movements when playing instruments, which is clearly observed in drums players for instance. In musicians, neural entrainment to music would unveil the ability to focus their attention in the synchrony between what they hear and how they move. Interestingly, musicians have also enhanced abilities to distinguish phonemes, such as /r/ as we mentioned above. This higher linguistic capacity would be secondary to musical practice.

Notably, in musicians seems clear that the training of musical rhythm processing would transfer to other domains such as speech, probably because the brain would be trained to synchronize with any sounds such as phonemes, syllables, words, and longer utterances.

Interventions supported by neural entrainment

Music interventions inspired by neural entrainment to music have been successful. For instance, after 2 years of participating in a music training program, primary school children from disadvantaged backgrounds showed that the ones who were more engaged in music training programs developed stronger brain responses during the recognition of phonemes and words boundaries of speech stimuli than their less-engaged peers in the program, and they also exhibited greater increases in reading scores[30].

Similar benefits have been found in preschoolers. The preschoolers who performed better in a drum-beat synchronization task, which demands the synchronization between auditory, sensorimotor, and other cognitive systems, showed greater pre-literacy assessments and have more synchronic brain response to the rhythmic presentation of syllables, even when the syllables were presented with background noise[31].

Interestingly, other rhythmic activities such as finger tapping to beat are poorly performed in children with dyslexia and specific language impairment[32].

Finger tapping to beat is a simple task but involves a precise sensorimotor synchronization between the auditory beat and the rapid and brief action of moving the finger[33]. Tapping to the beat is poor in all infants and young children and improves with age, although at any age there are good and bad tappers[34] and musical training improve it. However, until now the training of this simple motor activity has not shown strong and systematic benefits on auditory or speech processing or on reading. Probably tapping to the beat is tooo simple and rhythmic interventions may need higher levels of awareness about how the training improves the performance to transfer to linguistic and reading skills. Anyhow, future research is necessary to evaluate if the training of finger tapping to the beat, one of the most basic rhythmic sensorimotor actions, may benefit other cognitive abilities.

Together, music data support the model where rhythm, auditory, reading, and pre-reading processing transfer they training to each other during early childhood, and the format of this transfer would be at least partially the neural entrainment to rhythmic sounds.

Neural entrainment during interpersonal interactions

If the brain can entrain with speech, music, and probably with other external stimuli, it is expectable that it can entrain the interactions with other persons. Indeed, from a very early age, infants react with different behaviors and different brain activity when they interact with other people in face-to-face interactions[35]. Turn-taking is also observed from early age in games such as peak-a-boo, and rapidly develops to advance toward conversational interactions. Thus, recent exploratory studies have reported that neural entrainment also occurs with respect to social interactions during a conversation. Indeed, the brain not only entrains to the speech stimuli of other speakers but also entrain to the turns for speaking[36,37].

Message for educators

Neural entrainment to speech and music are supported and inspired rhythmic interventions aimed at improving linguistic abilities in children. This is the case of the training with music, which seems to benefit speech processing in typically and atypically developing children.

A number of rhythmic activities are not dangerous but in contrast, could help the developing brain to process rhythmic environmental stimuli and learn. Caregivers singing lullabies and bouncing their children, infants, and young children clapping, drumming, jumping, and practicing many other rhythmic activities are spontaneously observed in any culture. Although more research is needed to recommend particular activities, early childhood educators and parents may benefit from implementing systematic rhythmic practices, which may promote language and communication in a safe way. Adults and children studies showed that rhythmic practices modify the way how the brain process external stimulation and may provide the mind with more tools to confront learning.

Message for policy makers

Investing in more research about neural entrainment and promoting data-based rhythmic interventions during early development may help counteract at least partially some of the biological adversities when children develop and grow up in disadvantageous conditions. Such actions would serve as preventive and remedial initiatives for language difficulties, which will certainly improve children's wellbeing.

Training the brain to entrain with rhythmic activities involves non-expensive, ecologic, and ludic practices and may benefit the learning of some children who for different reasons have not had the opportunity to access to enriched rhythmic stimulation such as music or have not been trained to exploit them.

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