Effects of Musicality and Executive Function on Speech Auditory-motor Synchronization in Mandarin-speaking Individuals

Min ZHU and Fei CHEN
School of Foreign Languages, Hunan University, Changsha, China

Purpose: Auditory and motor functions are strongly coordinated in the perception and production of sounds via neural entrainment, not only in music but also in speech. It was widely recognized that humans possess an innate capability to synchronize their motor movements with external auditory rhythms, such as finger tapping or running to the music, which is known as auditory-motor synchronization. While previous studies have mainly focused on how non-speech signals entrain gross motor movements, the synchronization between auditory and vocal rhythms and its influential factors received little attention. Recently, the spontaneous speech-to-speech synchronization (SSS) test has been shown to be an effective behavioral method to examine speech perception-production links, by estimating the phase locking value (PLV) between auditory input and motor output as an indirect index of cortical auditory-motor coupling strength. The SSS test has been extensively validated in stress-timed languages, which demonstrated that the higher synchronizers could better match their speech output to the perceived rhythm, whereas the low synchronizers maintained weaker synchronization between speech input and output. Despite this, there is a lack of empirical evidence from other languages with different rhythmic structures, for example, syllable-timed languages like French or Mandarin. This study aimed to utilize the SSS test to quantitatively assess the degree of speech auditory-motor synchronization in Mandarin-speaking adults and explore its influential factors through a series of behavioural assessments.

Method: Forty healthy subjects were recruited to participate in SSS tests under both speech and music auditory conditions, respectively. Half of them were amateur musicians (mean = 5.7 years). They were exposed to a stream of randomly presented sounds (monosyllables or musical notes) at an accelerating rate (mean = 4.5 Hz) while being instructed to whisper /ma/ to their best in synchrony with the auditory stimulus rhythm. Each auditory sequence lasted approximately 70 seconds. Participants' PLVs between perceived and produced envelopes were computed. Furthermore, they were assessed for their musicality and executive function. Specifically, musicality assessment was conducted via the Goldsmiths Musical Sophistication Index questionnaire, while executive function was evaluated from three aspects: inhibitory control (Flanker test), working memory (digit span and nonword repetition tests) and cognitive flexibility (Wisconsin card sorting test).

Results: Musicians achieved significantly higher level of rhythmic synchronization than non-musicians. Moreover, there were no significant differences in PLVs between speech and music domains (Figure 1), indicating a shared domain-general mechanism underlying rhythmic processing. It was further confirmed by a strong correlation (r = 0.84, p < .001) between speech and music PLVs. In addition, multiple linear regression analyses were performed on PLVs of speech and music, respectively. It was found that only musicality and digit span scores significantly predicted individual differences in auditory-motor synchronization under both speech and music conditions (Figure 2). The findings corroborated the facilitative effects of musical ability and working memory on auditory and

speech processing. Specifically, musical ability is closely related to brain activation in the auditory and premotor cortices with musical training enhancing the left arcuate fasciculus that connects temporal auditory regions with frontal speech production areas. Furthermore, regarding cognitive ability, working memory recruits the prefrontal and posterior parietal cortices, which overlap with the network underlying speech processing. Moreover, the facilitative effect of working memory on speech auditory-motor synchronization might be accounted for by attention. As a main component of working memory, attention is highly involved and responsible for rhythmic possessing.

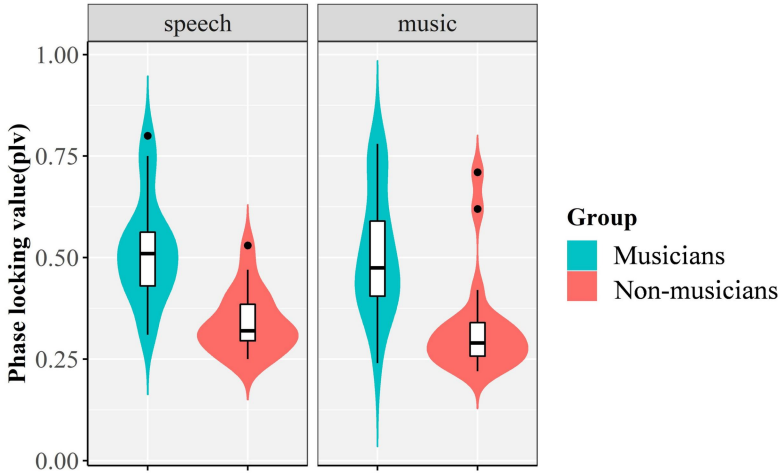

Figure 1. Mean phase locking values as a function of domain (speech vs. music) in musicians and non-musicians.

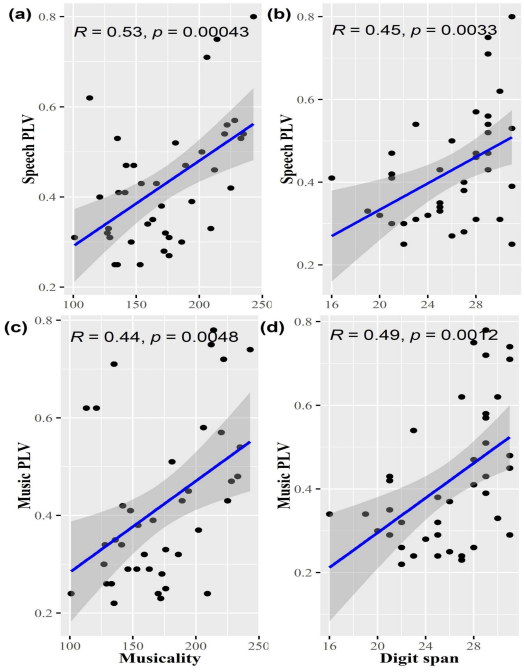

Figure 2. Relationship between phase locking values in the speech (a, b) and music (c, d) domains and individual differences in musicality and digit span scores.

Conclusions: Overall, this study confirmed the applicability of the SSS test in syllable-timed languages and provided valuable insights into the link between language and the brain. Additionally, the results have implications for speech intervention using musical and cognitive training, particularly for individuals with developmental speech and language disorders who may struggle with rhythmic processing.

Keywords: Rhythmic processing; speech; auditory-motor synchronization; music; executive function