Auditory information organizes human movement: Evidence from street dancers

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Abstract: Central nervous system utilizes the auditory information to organize movement. In turn, the auditory information itself organizes human movement. For example, auditory information affects movement trajectory and increases amplitude during rhythmic oscillating movement. Another example is a spontaneous pattern formation between rhythmic movement and auditory beat. We found that during street dance technique, phase relation between movement and auditory beat was spontaneously entrained into a specific one. We will introduce these self-organized phenomena between rhythmic movement and auditory beat, and the effect of sensorimotor learning on them.

Keywords: Dance, sensorimotor synchronization, dynamical systems approach

1. Bidirectional linkage between auditory information and movement

Humans dance to music or play musical instruments with others. In such situations, we use auditory information as a reference to produce our movements that are synchronized to it. On the other hand, increasing number of studies have shown that the auditory information itself modulates or organizes human movement. For example, proper use of auditory information promotes rehabilitation of movement disorders such as Parkinson's disease (for reviews, [1, 2]), or of stroke patients [3, 4]. Another example is that auditory beat strengthened a locomotor-respiratory coupling, which leads to reduced energy expenditure [5].

In this paper, we would like to introduce our previous studies [6-9] that reported other evidences that auditory information itself can modulate and organize human movement.

2. Auditory information increased movement amplitude and decreased noise in rhythmic movement

Kudo et al.[6] investigated the effect of auditory information on rhythmic movement. In their experiment, participants were instructed to swing two handheld pendulums with one in each hand to a metronome beat in in-phase manner in a sitting posture. There were two conditions. In single-beat condition, they were instructed to swing the pendulums with the beat at the most forward position of the pendulum. In double-beat condition, they were instructed to swing the pendulums with the beat at the most forward and backward positions. Results showed that in the double-beat condition, the amplitude of movement (angular displacement of the pendulums) significantly increased compared with that in the single-beat condition. In addition, they performed cross recurrence quantification analysis (CRQA) on the angular displacements of the two pendulums. The CRQA quantifies the features of movement trajectories reconstructed into higher dimensional state space. This analysis revealed that additional auditory information helped to stabilize the rhythmic movement pattern by increasing attractor strength and decreasing noise in the sensorimotor system.

3. Spontaneous pattern formation between auditory information and movement

Another example is a spontaneous pattern formation between auditory information and rhythmic movement. Our previous research showed it in street dance technique [7, 8]. In street dance, there are two basic phase locking patterns between repetitive knee-bending movement in stance and the musical beat: down-on-the-beat and up-on-the-beat. In the down-on-the-beat, dancers match the phase of knee flexion on the beat, while in the up-on-the-beat dancers match the phase of knee extension on the beat. In the Miura et al.[7], both street dancers and non-dancers were instructed to perform each phase locking pattern to a metronome beat whose rate increased in a stepwise manner from 1 Hz to 3.7 Hz. They were instructed to keep 1:1 phase relation between the beat and knee-bending movement, and not to resist a change of the phase locking pattern. Both street dancers and non-dancers were able to maintain the down-on-the-beat pattern stably across all the beat rates. On the other hand, in both groups the up-on-the-beat pattern spontaneously and unintentionally transited to the down-on-the-beat pattern at high movement frequencies. Note that they were able to move fast enough to match the beat, which was confirmed in the down-on-the-beat. Also note that the phase transitions from the up-on-the-beat to the down-on-the-beat was not due to the difference of frequency between the beat and the movement because one phase locking pattern (i.e., up-on-the-beat) was changed into the other phase locking pattern (i.e., down-on-the-beat). The critical frequency where the unintentional transition from the up-on-the-beat to

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down-on-the-beat occurred was significantly higher in the street dancers (2.8 Hz) than in the non-dancers (2.1 Hz). The same phase transition phenomena was observed in finger-to-beat coordination [9].

What happened if the participants were instructed to resist the phase transition as much as possible? Miura et al.[8] investigated this up to 3 Hz. Although the street dancers resisted the phase transition at higher beat rates than did non-dancers, all participants except for one dancer could not resist the phase transition. Noteworthy result was that a skilled street dancer was able to maintain the up-on-the-beat at 3 Hz.

These results suggest that such intrinsic tendency for auditory-motor coordination may be an obstacle for some motor skills such as those in street dance or playing musical instruments. The intrinsic tendency must be overcome by practice in such situations. The important implication from these studies is that movement frequency is a key control parameter that is associated with spontaneous pattern formation between auditory information. Future study is needed to clarify that what frequencies would be effective for overcoming such intrinsic tendency during the practice of auditory-motor coordination.

4. General discussion

These findings we mentioned in the section 2 and 3 indicates that human have intrinsic tendency between auditory information and movements. There is one interesting explanation for the intrinsic tendency in terms of evolution [10]. A cognitive scientist Matz Larsson [10] argued that self-generated sounds of locomotion and ventilation is related to human rhythmic abilities. He argued that such self-generated sounds would mask critical sounds in the environment, so our ancestors needed to synchronize walking with people in small group in order to reduce the masking properties of locomotion sounds. The central nervous system for such intrinsic tendency of auditory-motor coordination (e.g., unintentional entrainment) may be evolved for this purpose. This also gives a rationale for unintentional synchronization of human gait [11, 12].

Along with the studies on the effect of auditory information on rehabilitation mentioned in the section 1, our findings suggest that a proper use of auditory information would improve our sensorimotor learning because auditory information itself changes our movements. Designing auditory environment for effective sensorimotor learning is an interesting theme for future study.

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