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Phase Transitions in Coordination of the Wrist to Other Body Parts at Different Tempi in Professional Drum-set Players

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Professional drum-set players (henceforth drummers) must coordinate different body parts to play the component instruments at the requested tempo. For example, previous studies on the performance of professional drummers revealed that stick trajectory is regulated differently depending on the performance tempi (Dahl, 2011), while the synchronization error of taps against the metronome sound differed according to the instrument (hi-hat cymbals, snare drum, and bass drum) (Fujii, Hirashima, Kudo, Ohtsuki, Nakamura, & Oda, 2011). However, it remains unclear to what extent motor coordination among different body parts underlie the performance of professional drum-set players.

Research on motor control has shown that spontaneous phase transitions from an unstable pattern (i.e., anti-phase mode) to a more stable pattern (i.e., in-phase mode) occur when movement frequency exceeds a critical point. Phase transitions (and/or phase wandering) have more recently been found in practical tasks such as dance-like knee bending or extension movement tasks (Miura, Kudo, Ohtsuki, & Kanehisa, 2011), as well as in the unimanual or bimanual tapping of a drum using drum sticks (Fujii, Kudo, Ohtsuki, & Oda, 2010). As noted earlier, in professional drum-set playing, different body parts are involved in playing different instruments. However, what patterns of coordination can be observed between wrist movements and the movement of other body parts at different performance tempi? The present paper reports on work-in-progress aimed at answering this question.

Method

Three professional drummers participated in this study. At the time of the experiment, Expert 1 was 25 years old and had 10 years of drum-set playing experience; Expert 2 was 38 years old and had 27 years of experience; and Expert 3 was 34 years old and had 21 years of experience. They each performed an eight-beat rhythmic task using an electric drum-set (TD-25, Roland) comprising hi-hat cymbals, a snare drum, and a bass drum, at different tempi

(60, 120, and 180 beats per minute) specified by metronome beeps. While performing the task, participants listened through headphones to the sound of their drumming as they produced it, while also listening to the metronome beeps through audio speakers. The tap pressure of each instrument and the metronome beep signals were acquired at a sampling frequency of 1000 Hz. In addition, the three-dimensional (3D) motion data of each participant was obtained with a 3D opto-electronic motion-capture system (Opti Track, Natural Point Inc.) at a sampling frequency of 100 Hz. Each trial lasted for approximately 30 seconds. To capture the motion data, we placed 15 spherical reflective markers across the participant's body, including the top of the head, neck (seventh cervical vertebra [C7]), back (twelfth thoracic vertebra), shoulders (acromion), elbows, wrists (ulnar head), thighs (greater trochanter), knees, and ankles.

The targets of the analysis were the four bars (32 hi-hat cycles) after the first three bars following measurement onset. This was to eliminate the initial period where performance tends to be unstable. The tap pressure data were centred on zero, full-wave rectified, and analyzed to obtain the tap peaks. Specifically, the metronome signals were Hilbert transformed to obtain the envelopes of each tap signal (see Fujii et al., 2011), from which we determined the tap peaks. As an index of performance accuracy, the synchronization error of the tap peaks with the metronome peaks of each instrument was calculated.

The time series of the movements of each of the body parts were band-pass filtered (6th order Butterworth filter, 0.8–10 Hz, bidirectional) and centered on zero. Using the vertical displacement extracted from the 3D motion data, continuous relative phases of the right wrist and C7, the right wrist and right shoulder, and the right wrist and right elbow were calculated. The phase angles for each body part were calculated using the Hilbert transform (see Lamb & Stöckl, 2014).

To compare the coordination pattern for each tempo and the coordination of the body parts among the participants, we obtained the standard deviation of the continuous relative phases (Figure 1), the synchronization error by tempo (Figure 2), and the histogram of continuous relative phases (Figure 3).

Results and Discussion

As shown in Figure 1, the *SD* of the continuous relative phases in the 180 bpm condition was smaller than those in the 60 or 120 bpm conditions (Figure 1). As for the synchronization error of the taps against the metronome beeps according to tempo, the results indicated that the higher the tempo, the smaller the error (Figure 2). Additionally, the taps tended to follow the metronome beeps at 60 bpm and 120 bpm, but to be slightly ahead of the beeps at 180 bpm (Figure 2). These results correspond to those of a previous study on professional drummers (Fujii et al., 2011).

Figure 3 shows the distribution of relative phases between the right wrist and the other body parts according to the tempo. We observed different patterns of distribution in the relative phases across participants in the 60 and 120 bpm conditions (the upper and middle panels of Figure 3), while in the 180 bpm

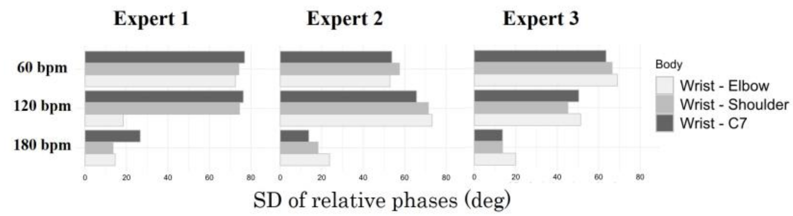

Figure 1. The standard deviation (*SD*) of the continuous relative phases for all subjects.

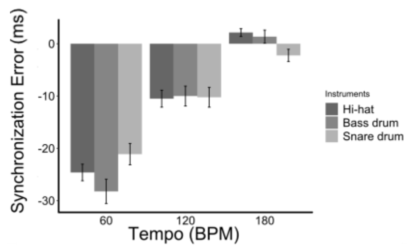

Figure 2. The synchronization error by tempo

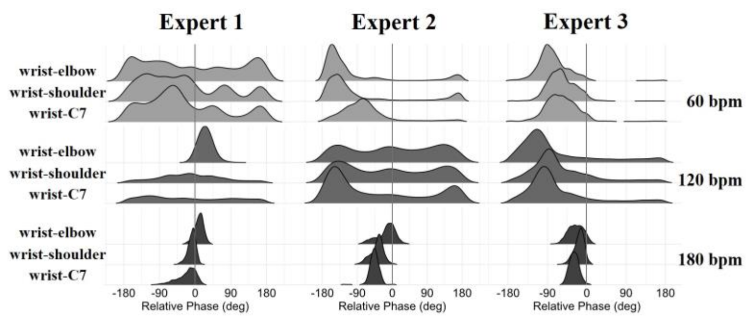

Figure 3. The histogram of continuous relative phases of the right-wrist to other body parts.

condition, we observed only one pattern with a single peak at around 0 degrees (the lower panels of Figure 3). These findings suggest that phase transitions from the various relative phase modes to the in-phase mode occurred somewhere between 120 bpm and 180 bpm.

Next, we explored the various coordination patterns for different players in the slower to medium tempo conditions. At 60 bpm, the distribution of the three relative phases showed multiple peaks for Expert 1, although the distribution tended to be denser in the negative domain than in the positive domain; this finding suggests that movement in the wrist preceded that of other body parts (the upper-left panel of Figure 3). This pattern was also found for the wrist–shoulder and the wrist–C7 relative phases in the 120 bpm condition for this participant, whereas the wrist–elbow relative phase had a single peak at approximately 30 degrees (the middle-left panel of Figure 3).

For Expert 3, the distribution of the wrist–elbow relative phases in the 60 bpm and 120 bpm conditions had single peaks at approximately -90 degrees, while the distributions of the wrist–shoulder and the wrist–C7 had single peaks at approximately -60 degrees (the upper- and middle-right panels of Figure 3). These findings indicate that, for each tap, wrist movement constantly preceded movement in the shoulder and the C7, which were in turn followed by the elbow.

Expert 2 exhibited mixed patterns in the 60 bpm and 120 bpm conditions. At 60 bpm, the pattern is comparable to that of Expert 3 in that the wrist–elbow and the wrist–shoulder relative phases peaked at around -180 degrees, while the wrist–C7 relative phase peaked at about -90 degrees (the upper-center panel of Figure 3). At 120 bpm, the distribution seemed more dispersed, with peaks at ±180 and 0 degrees, making it similar to those in the 60 bpm and 120 bpm conditions for Expert 1 (the middle-center panel of Figure 3).

Taken together, the findings indicate that in the slow and medium tempo conditions, two professional drummers showed a change in the phase relationship between wrist movement and movement in other body parts as they proceed through the task, whereas the other player kept a relatively constant coordination pattern. In other words, professional drummers had some room to vary the way in which they coordinated their body to perform the task. At the fastest tempo in this study (i.e. 180 bpm), however, the body parts under scrutiny were in the in-phase mode for every participant, indicating that players have relatively little space to perform differently from others at this fast tempo. The findings also imply that between 120 and 180 bpm is a critical point for the occurrence of phase transitions, which will be examined in a future study.

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