Cooperative Rhythm Production between Three People through Auditory Signals

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Abstract:
The purpose of this study was to investigate the characteristics of cooperative rhythm production between three people and the effect of cross-feedback between people on the cooperation. We conducted an experiment in which two mutually isolated followers simultaneously performed a synchronized-finger-tapping task with a human leader or metronome producing constant tempo. The followers performed this task with or without tapping timing information of the other follower. The leaders were asked to tap their finger to keep constant tempo with or without the tapping time information of followers. The cross-feedback between followers enlarged synchronization error. The cross-feedback between a leader and followers shortened their inter-tap intervals (ITIs) and decreased the standard deviations of ITIs. These results suggest that the cross-feedback between people in synchronized tapping did not contribute the accuracy of timing of tapping but the variability of tapping timing.

1. INTRODUCTION

As evidenced in music ensemble, conversation, dance and sports, we cooperatively produce rhythm with other people. Such temporal interaction between multi people is achieved through processing of signals from other people and self and movement to the environment based on the signals. This process includes many time delays: delays included in signal processing, multi-modal integration and sensory-motor coordination. In addition, there are also some delays in transferring of signals between people. Despite of such many delays, people rhythmically generate movement cooperatively with others in real time. The characteristics of temporal cooperation between people, especially over three people, however, unclear yet

Finger tapping task is a simple task to investigate the characteristics of temporal cooperation to sensory signals from environment [1-3] (see also review, [4]), including other people [1,2,5-7]. In this task, participants tap with their finger in such a way as to be synchronized with signals presented from metronome or a partner through auditory, visual or/and tactile sensation. It is well known that in synchronized tapping with constant tempo metronome, people tend to tap a few tens of milliseconds before metronome stimuli and they were generally not aware of the asynchrony [4,8,9]. This phenomenon is called negative mean asynchrony (NMA).

Mates and his colleagues investigated the effect of cross-feedback on sensori-motor synchronization using cooperative tapping task. In this task, participants were synchronized to a constant-tempo metronome using finger tapping with or without a partner who was simultaneously synchronized to the metronome. In cross-feedback condition, the participants were presented the timing information of the partner's tapping as tones with each other. As results, they concluded that the cross-feedback information did not contribute the accuracy of tapping timing in synchronized tapping task with metronome.

This result, however, was because the metronome which was not affected by participants' tapping timing was target to be synchronized with. Ogata *et al.* investigated the difference between synchronized tapping with metronome and that with a partner using alternate tapping task [2]. In this task, participants alternately tapped with metronome or a partner to keep a target tempo. As results, the averaged durations between tapping timings of a participant and a partner were more accurate than that between the participant and the constant-tempo metronome. Moreover, the variability of tapping timing in rhythm production with a partner was smaller than that with constant-tempo metronome. These results suggest that cross-feedback information in synchronized tapping task with a human leader may contribute the accuracy of rhythm production. Or, increase of cross-feedback with a human leader and the variability of leader's tapping timing may decrease the accuracy.

The purpose of this study was to investigate the characteristics of rhythm production between three people. For this purpose, we conducted the synchronized tapping task with a human leader or metronome with or without a partner.

2. EXPERIMENT

2.1 Participants

Nine people participated in our experiment. They ranged in age from 21 to 32 and were all male and right handed. They were divided into groups in three.

2.2 Apparatus and Stimuli

Fig. 1 shows the experimental apparatus. All signals were produced and measured by the interface (Custom-made; DKH Corp.) controlled by the specialized program (Custom-made; DKH Corp.) on the PC (Dimension 8300; Dell Corp.). Tapping timing was measured by pressure sensors (PH-464; DKH Corp.). Auditory stimuli were presented by

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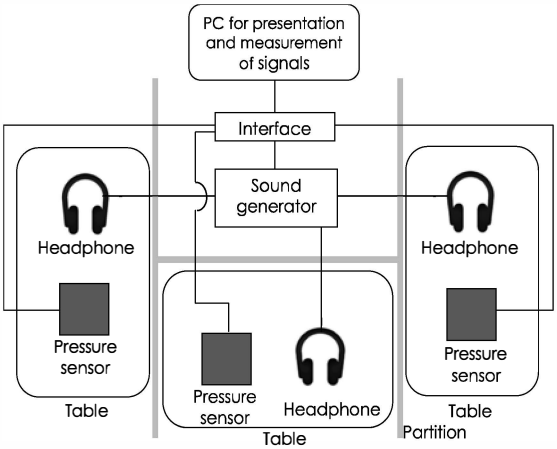


Fig. 1 Experimental apparatus.

sound generator (Custom-made; DKH Corp.) via headphones (ATH-T200; audio-technica). The auditory stimuli were rectangular wave and their frequencies were 500, 1,000 or 2,000 Hz. Time resolution of presenting and measurement of signals was one millisecond.

2.3 Task and Conditions

The two followers were presented the same tone sequence from a metronome keeping regular tempo (700 ms) or from a human leader trying to keep regular tempo (700 ms) by finger tapping. The follower's task was to be synchronized by finger tapping with the metronome or the human leader.

The human leader was asked to keep the tempo of a pacemaker presented before the leader started finger tapping. The pacemaker had eight stimuli and its tempo was 700 ms at the same tempo to the metronome. When the human leaders were presented the stimuli of followers' tapping timing, the leaders were asked to try to ignore the stimuli and to keep the tempo, 700 ms.

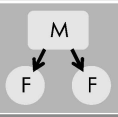
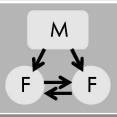
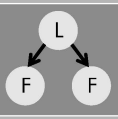
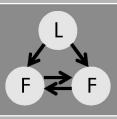
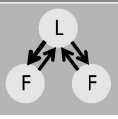
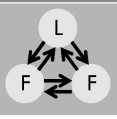
As shown in Table 1, there were two between-followers-feedback conditions: (1) no feedback (F_NFB) condition, where the each follower was not presented any feedback stimuli from the other follower and (2) crossed feedback (F_CFB) condition, where the each follower listened to auditory stimuli corresponded to the timing of the other follower's tapping.

In addition, there were three leader conditions: (1) constant tempo metronome (M) condition, (2) a human leader without any feedback of followers' tapping timing (H_NFB) condition, where the human leader was presented no external stimuli and (3) a human leader with crossed feedback between a leader and followers (H_CFB) condition, where the leader listened to auditory stimuli corresponded to the timing of two followers' finger tapping.

2.4 Experimental Design

The experiment had twelve conditions (participant's role conditions (leader or follower) × two between-followers-feedback conditions (F_NFB or F_CFB) × three leader conditions (M, H_NFB or H_CFB)).

Table 1 Two between-followers-feedback conditions and three leader conditions. M means metronome. L and F are a leader and a follower. The arrows indicate presentation of stimuli of metronome or other peoples' tapping timing. FB means feedback.

	No FB between followers (F_NFB) condition	Crossed FB between followers (F_CFB) condition
Constant-tempo metronome (M) condition		
Human Leader with no FB (H_NFB) condition		
Human Leader with crossed FB (H_CFB) condition		

2.5 Procedure

At the first, three participants of a group were divided into one leader and two followers. The roles of each participant were maintained through the experiment.

Participants were seated and placed their right lower arm on the desk. They were asked to tap with their index finger. The position of the pressure sensor and the volume of auditory stimuli were adjusted with comfort before the experiment and the position and the volume were kept constant through the experiment. Participants wore an eye mask during trials. They were asked not to move their body parts except their index finger.

For participants to distinguish tones of metronome and the other participants, we prepared different frequencies for tones corresponding to metronome and each participant's tapping. The stimuli of metronome were presented as 500 Hz tone to all participants. The stimuli corresponding to the leader's tapping were also presented as 500 Hz to the followers. The followers' tones were 1,000 Hz and 2,000 Hz respectively.

At the first of trials, eight pacemaker stimuli were presented to all participants. The tempo of the pacemaker was 700 ms and the frequency of pacemaker's tone was 500 Hz. Following the pacemaker, leaders started finger tapping to keep the tempo and followers were synchronized to metronome or the human leader with finger tapping. The leaders were asked to ignore the stimuli from two followers and the followers were also asked to ignore the stimuli from the other follower.

The six experimental conditions (three leader condition ×two between-followers-feedback condition) were conducted four times. Therefore, the sum number of trials of one group was 24. One trial took about 1,800 ms.

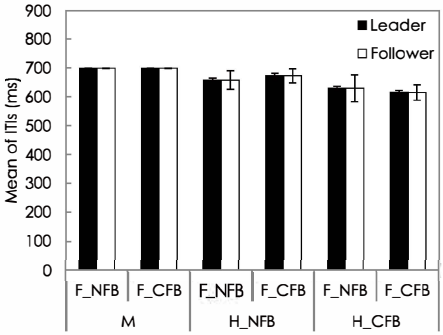


Fig 2 Means of ITIs between trials under each condition. The error bars represents the standard deviations between trials.

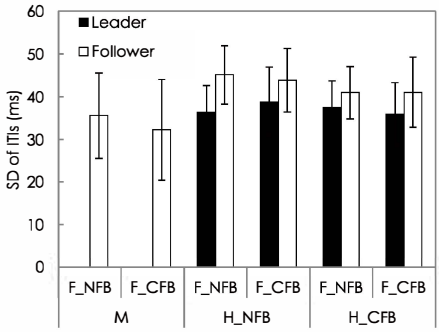


Fig. 3 Between-trials means of SDs of ITIs under each condition. The error bars represents the standard deviations between trials.

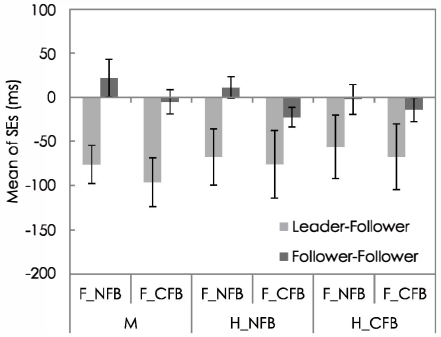


Fig 4 Means of SEs between trials under each condition. The error bars represents the standard deviations between trials.

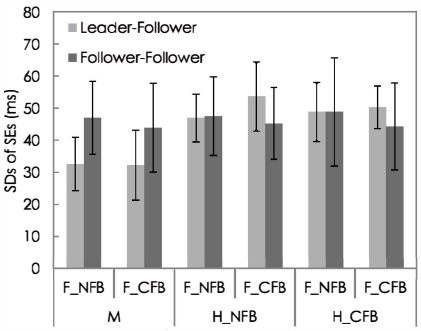


Fig. 5 Between-trials means of SDs of SEs under each condition. The error bars represents the standard deviations between trials.

3. RESULTS

We analyzed Inter-Tap-Intervals (ITIs) of each participant and Synchronization Errors (SEs) of tap timings between participants. ITIs are durations from onset of a tap of a participant to onset of the next tap of the participant. SEs are timing differences between onset of a tap of a participant and onset of the corresponding tap of another participant or metronome. For data analysis, we used 120 ITIs and 120 SEs per trial from 10th tap.

Fig. 2 shows within-trial averages of ITIs of leaders and followers. Tow-way repeated-measure ANOVA for averaged followers' ITIs of all conditions showed main effect of leader conditions (p<.001). There were neither main effect of between-followers-feedback conditions (p=.63) nor interaction (p=.08). Multiple comparisons by Ryan's method showed significant differences between M and H_NFB conditions, between M and H_CFB conditions and between H_NFB and H_CFB conditions. As the results, ITIs of followers in human-leader conditions were smaller than those in metronome-leader condition. Compared between human-leader conditions, ITIs of followers in H_CFB condition were smaller than those in H_NFB condition.

By three-way factorial ANOVA for averaged leaders' and followers' ITIs in participants' role conditions, between-followers-feedback conditions and two human-leader conditions except M condition, there was main effect in leader-conditions: H_NFB and H_CFB conditions (p<.001). There were neither main effect of participant's role conditions (p =0.99) nor between-followers-feedback conditions (p= 0.59) and there were not any interactions (all: p>.05). Compared between human-leader conditions, not only follower's ITIs but also leader's ITIs in H_CFB condition were smaller than those in H_NFB condition.

Fig. 3 depicts between-trial averaged standard deviations (SDs) of ITIs in each condition. Tow-way repeated-measure ANOVA for averaged SDs of ITIs showed main effect of leader conditions (p<.05). There were neither main effect of between-followers-feedback conditions (p>.05) nor interaction (p=.15). By Ryan's methods, there was significant difference between M and H_NFB conditions. There was neither significant difference between M and H_CFB conditions nor between H_NFB and H_CFB conditions. That is, only under H_NFB condition, the variability of ITIs was higher than that under the other two leader conditions.

Fig. 4 shows between-trials averaged SEs of each condition. In all conditions, averaged SEs between a leader and a follower were negative. That is, followers tended to tap before the timing of metronome or leader's taps. By three-way factorial ANOVA in the condition whether SEs were between a leader and a follower or between followers (SEs conditions), leader conditions and between-followers-feedback conditions, there were main effects between SEs conditions (p<.01) and between-followers-feedback conditions (p<.05). There was neither main effect of leader condition (p=.87) nor interaction (all: p>.05). The amount of negative asynchrony under F_CFB condition was larger than that under F_NFB condition.

Fig. 5 depicts between-trial averaged SDs of SEs in each condition. In the same way as averaged SEs, we used three-way ANOVA for SDs of SEs. There were no main effects of SEs conditions (p=.57), leader conditions (p=.10) or between-followers-feedback conditions (p=0.57). There were no interactions (all: $p > 0.05$). That is, both leader conditions and between-followers-feedback conditions did not affect the SDs of SEs.

4. DISCUSSION

In synchronized tapping with metronome or a human leader, cross-feedback between followers affected only averaged SEs but did not have effects on averaged ITIs, SDs of ITIs and SDs of SEs. Mates *et al.* found that cross-feedback between followers enlarged NMA in synchronized tapping with metronome [5]. In the present experiments revealed that also in synchronized tapping with a human leader cross-feedback increased NMA and that the amount of increase of NMA was not different between leader conditions.

NMA is usually unconscious phenomenon for the self to produce rhythm with signals from environment [4,8,9]. The amount of NMA is, however, enough for other people to perceive. Therefore, the increase of follower's NMA in cross-feedback conditions would be caused by tapping timings of the other follower who tapped a few ten milliseconds before leaders. While participants distinguished two partners' tones by the tone's frequency, it is known that people cannot completely ignore the effect of irrelevant signals on rhythm production [4].

Leader conditions did not affect averaged SEs or SDs of SEs but averaged ITIs and SDs of ITIs. Moreover, averaged ITIs under H_NFB condition were smaller than those under M condition. In continuous tapping task which participants tap to keep the tempo of pacemaker stopped at the start of tapping, the tempo of participants had become small compared to the pacemaker [2]. In the present experiment, the averaged ITIs of leaders were smaller than pacemaker's tempo (700 ms). This shortening of leader's tempo would decrease followers' ITIs.

Furthermore, the averaged ITIs under H_CFB condition were even smaller than those under H_NFB condition. In alternate tapping task between two people, cross-feedback between participants decreased ITIs [2]. Therefore, the additional decrease of ITIs under H_CFB condition would be caused by cross-feedback between leaders and followers.

The SDs of SEs under H_NFB condition were larger than those under M condition. It would appear that the variability of leaders' tempo increased the variability of followers' tempo. The SDs of SEs under H_CFB condition were, however, not smaller than those under M condition but smaller than those under H_NFB condition. These results suggest that cross-feedback between leaders and followers decreases the variability of tapping timing.

Synchronized tapping between people was investigated from the view point of temporal variation using time series analysis [1,2,6,7]. For example, in alternate tapping task with a human partner, people tried to match their tempo with a partner's tempo and to change the duration between onsets of own and the partner's tapping in a mutually complementary manner [2]. That is, if the partner increased the duration between own and the partner's timing, the participants decreased the duration on the next tap and vice versa. In the future work, dynamic characteristics of temporal cooperation between multi people should be revealed by analyzing temporal variation in synchronized tapping between three people.

5. CONCLUSION

To investigate characteristics of temporal cooperation between three people, we performed synchronized tapping task with metronome or a human leader with or without a partner who are synchronized together with the same leader. The cross-feedback between two followers increased negative mean asynchrony between leaders and followers. The cross-feedback between a leader and a follower accelerated averaged tempo of participants but decreased the variability of tempo. These results revealed that cross-feedback between three people in synchronized tapping task did not contribute the accuracy of tapping timing but the decrease of variability of tapping tempo.

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