Timing with Different References

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***Abstract*—Most of the people have the ability to feel and reproduce a tempo. We tested how well can people synchronize tapping of their finger to the sequence of sound stimuli with isochronous versus linearly speeding up and slowing down tempo and keep up with the pace after the metronome sound stops. The participants were able to synchronize with isochronous and gradually changing tempo accurately and the difference between their performances on steady versus changing tempo was not that significant. The continuation part showed that participants had significantly bigger problem to continue tapping to the speeding up tempo, than to the slowing down or isochronous tempo.**

I. Introduction

People coordinate their actions with the audible actions in order to synchronize them. The dancers time their movement to music, the members of an orchestra synchronize their playing with each other. During these actions, an internal synchronization is generated, which enables listeners to follow events as they unfold in time and helps them to predict the future events. [1] Musicians use the internal synchronization when they are practicing, or recording with a metronome to pace their actions. This form of referential behavior, when a predictable external event serves for temporal coordination is called sensorimotor synchronization [2].

The sensorimotor synchronization with an isochronous sequence was explored e.g. in [3] by finger tapping. However, the isochronous operation is not the only form of rhythmic performance. A gradual slackening in tempo can be produced by an ensemble of musicians with a good accuracy [4]. Therefore, a human ability to synchronize with a linearly changing tempo was studied in [5]. Madison concluded that synchronization was accurate for increasing and decreasing tempo. The accuracy of beats produced after the metronome sound went off was tested as well in the continuation phase. Another conclusion was that the continuation intervals change in the reverse direction of the stimulus sequence intervals. The participants were not tapping with their fingers, but beating a drumstick against a drum pad in this experiment.

Similar study [6] in which the responses were obtained by finger tapping revealed that the tapping with increasing frequency is more difficult to perform. The electromyographic recordings of the test with decreasing interonset intervals (IOI) were comparable to those obtained in the test with the constant frequency condition.

Another study [7] measured the accuracy of finger tapping to the musical phrases in which the tempo increased or decreased both at the beginnings and ends. The results showed that musicians coordinated their actions better with a decreasing than increasing tempo.

Based on previous research conducted in this area we construct our hypothesis as follows. People are able to synchronize finger tapping to the gradually changing tempo just as well as to the isochronous tempo, but they are not able to continue tapping to the changing tempo as well as to the isochronous tempo after the synchronous sound fades away.

II. Method

A. Participants

Participants were recruited online at social network as the experiment was web-based. The number of people that participated in experiment is 52, however 10 instances were removed, because they contained errors that might have occurred due to the misunderstanding of the instructions. The number of participants that submitted correct data is 42.

The information about participants was collected using survey questions that can be seen in the appendix. The answers showed that the whole group contained 12 women and 30 men. Ages were between 18 and 44 years with a class median interval from 25 to 34. The number of participants who do not play any musical instrument is 11 and the number of participants who do not have a formal musical training is 14 (M = from 1 to 3 years). The specifics can be found in tables in the appendix. None of the participants were compensated for their participation.

B. Materials

The stimuli consisted of three sound sequences. Each sound sequence contained 32 metronome sounds with fast attacks and lengths of 50ms downloaded from free web-based sound library[1]. Matlab [8] was used to create the metronome-like sequences. The isochronous sequence had equal IOIs of 500ms, while each successive interval in the linearly changing sequences was either shortened or lengthened by 5ms. This value of 5ms was chosen, because the pilot experiment in [5] established that sound sequence with at least $\pm$4ms change is clearly recognizable as a changing tempo. Second reason was that the IOIs in the synchronization and also in the continuation part had to be in a range in which the synchronization is still possible. For hand tapping, the upper limit of this range was approximately set to 150-200ms and the lower limit to 2s in [9]. The length of IOIs before last taps of individual sequences in the continuation parts were 500ms, 250ms and 750ms.

The experiment was conducted online with a custom-designed web-site that provided the instructions, generated the sound sequence, collected the times of responses, calculated the absolute asynchronies, collected the information about participants and stored the data from the first attempt to the comma delimited text file. This system has resolution of 1 ms. The participants could have used touchpad, or mouse for tapping.

[1] https://freesound.org/people/unfa/sounds/243749/

C. Design

The independent variable within participants was the amount of changing tempo -5, 0 and 5ms, which gives 3 conditions. Dependent variable was mean of asynchronies between correct times and responses.

The sequences were presented to every participant in the same order. First came isochronous, second speeding up and the last slowing down.

The survey was split into three parts. Every sequence was followed by one part of the survey, which served as a distraction.

D. Procedure

Anybody could participate in this experiment after opening one of the two links[2][3].

The opened web-site first provides written information about the character of the test, the required time and required version of the internet browser.

Second, the following written instructions are given: "TempoMeter consists of three parts. Each part starts with the metronome sound. After the text on the website changes from "Focus!" to "Tap Now!", you should start tapping the button using your touchpad or mouse. The metronome sound will go away after some time, but you should keep tapping to the tempo set by the metronome to the best of your abilities until the text changes to "Stop tapping". You will be automatically redirected to a short survey after each part. The surveys have to be submitted by clicking on the "Complete" button.

Use headphones during the test! The delay created by the speed of sound traveling in the air will be reduced to minimum by doing so. Set the volume using the following test sound to a comfortable level.

While performing this test, you should be in a quiet environment!"

The button which started the test was placed under the instructions. Each participant who completed the test saw the performance graph of relative error in the end.

E. Data Treatment

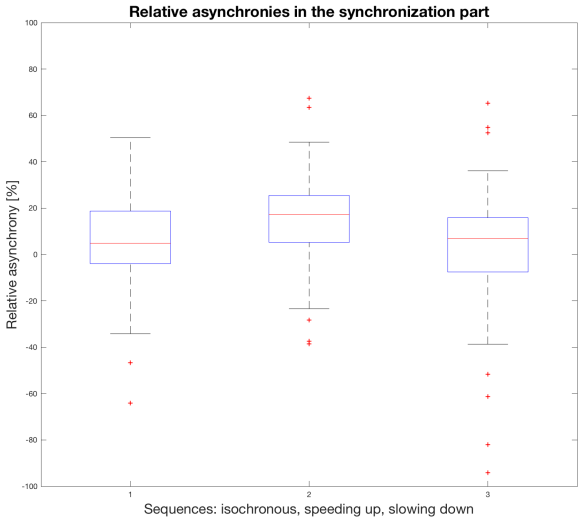
The participants were asked to start tapping after they heard 4 beats of the metronome, however the recording started after another 8 beats of the metronome. The synchronization part contains 20 responses and continuation part contains another 20 responses which gives 40 responses together. Absolute asynchronies were calculated by subtracting the recorded responses from the calculated correct times of responses. Each relative asynchrony was calculated by dividing the absolute asynchrony by preceding IOI.

III. Results

A. Synchronization

The mean asynchronies of each step in synchronization part were calculated across all participants. Kolmogorov-Smirnov test showed that these means were not equally distributed, therefore the Kruskal-Wallis one way analysis of variance was performed. The result was p = 0.0263 $<$ α = 0.05, therefore the null hypothesis that the medians of isochronous, speeding up and slowing down sequences in synchronization part are all equal was rejected.

However, the null analysis would not be rejected, if the significance level α was set to lower value e.g. 0.01. The following figure shows that the relative asynchronies of the tested tempos are not significantly different. Only the speeding up tempo had slightly worse asynchrony results in the synchronization part.



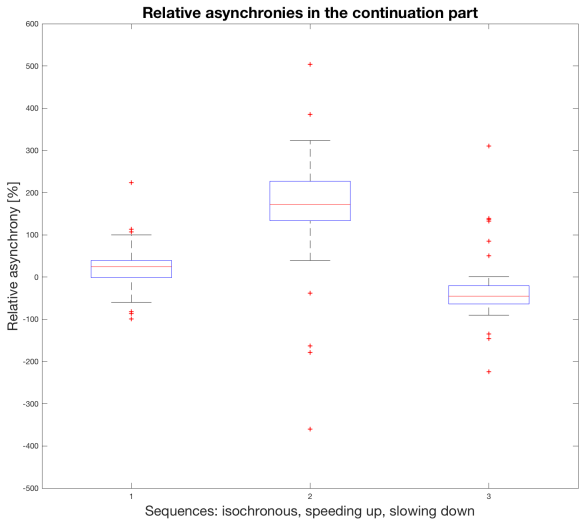
B. Continuation

The mean asynchronies of each step in continuation part were calculated across all participants. Kolmogorov-Smirnov test showed that these means were not equally distributed, therefore the Kruskal-Wallis one way analysis of variance was performed. The result was p $<$ 0.00001 $<$ α = 0.05, therefore the null hypothesis that the medians of isochronous, speeding up and slowing down sequences in continuation part are all equal was rejected.

The following figure shows that the relative asynchronies of the isochronous and slowing down tempos are slightly different. However the speeding up tempo had significantly worse asynchrony results in the continuation part.

[2]http://www.tempometer.ga/

[3]https://tempometer.000webhostapp.com/



IV. Discussion

The results show that the participants were tapping slightly worse while synchronizing to the speeding up tempo, than to the isochronous or slowing down tempo. The performance on the speeding up tempo in the continuation part shows even bigger asynchronies. These results support the conclusion in [6] which says that the tapping with increasing frequency is more difficult compared to the tapping with equal, or decreasing frequency and the conclusion in [7] that participants coordinate their actions better with a decreasing than increasing tempo.

The graphs of relative asynchronies in tested sequences, that can be found in the appendix, show tendency of continuation intervals to change in the reverse direction of the stimulus sequence intervals similar as in [5].

However, these results cannot be generalized, because they were concluded from an unbalanced group of participants with more men than women in age only between 18 and 34 years and more musicians than non-musicians. Another problem is, that the experiment was web-based, therefore we cannot guarantee the quality of the data. The web-based experiment was chosen, because we hoped that we can recruit more people from diverse groups, so we could compare the performance between them. However, the fact is that the experiment did not reach so many people and 10 data instances had to be removed, because of the significant errors.

We also realize that there were two problems with the experiment design. First was, that the order of testing tempos was the same for all the participants, which can have an influence on the results. Second was, that the volume of metronome sequence should have faded out smoothly. Some participants were shocked when the sound disappeared immediately and it influenced their results.

V. Conclusion

The participants were able to synchronize with isochronous and gradually changing tempo accurately and the difference between their performances on steady versus changing tempo was not that significant. The continuation part showed that participants had significantly bigger problem to continue tapping to the speeding up tempo, than to the slowing down or isochronous tempo.

Appendix

Survey questions

Question 1.
What is your gender?

a) Female b) Male

Question 2.
What is your age?

a) under 12 years old b) 12 - 17 years old
c) 18 - 24 years old d) 25 - 34 years old
e) 35 - 44 years old f) 45 - 54 years old
g) 55 - 64 years old h) 65 - 74 years old
i) more than 75 years old

Question 3.
Do you play any musical instruments?

a) No. b) Yes, from the group of percussion instruments.
c) Yes, from the group of wind instruments. d) Yes, from the group of stringed instruments.
e) Yes, from multiple instrument groups.

Question 4.
Do you have any formal musical training?

a) No. b) Yes, less than 1 year.
c) Yes, from 1 to 3 years. d) Yes, from 3 to 5 years.
e) Yes, more than 5 years.

Question 5.
Have you been counting during the tests?

a) Yes b) No

Participant information

none	11
percussion instruments	4
wind instruments	5
stringed instruments	14
multiple instrument groups	8

TABLE I: Do you play any musical instruments?

no	14
less than 1 year	4
1 - 3 years	4
3 - 5 years	2
more than 5 years	18

TABLE II: Do you have any formal musical training?

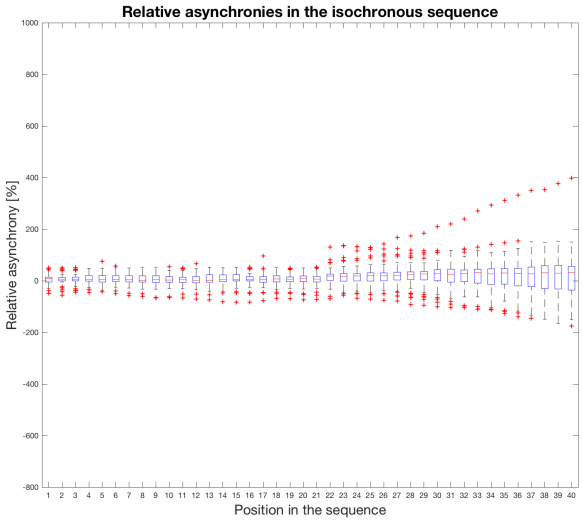
RELATIVE ASYNCHRONIES IN TESTED TEMPOS

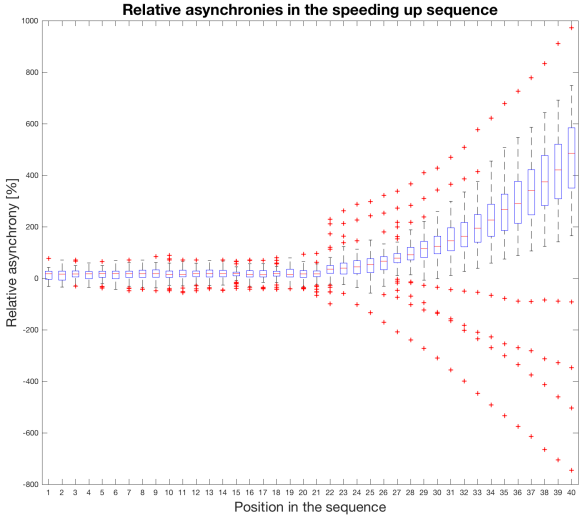
From position 1 to 20 - synchronization part.

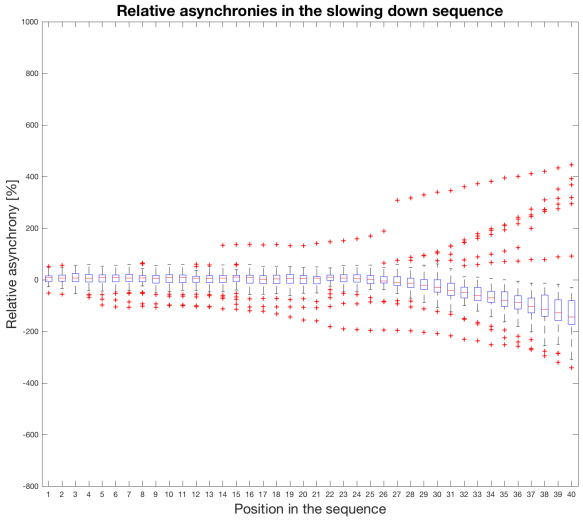
From position 21 to 40 - continuation part.

Negative asynchrony means that the tap occurred early.

Positive asynchrony means that the tap occurred late.







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