Quantifying the strategy taken by a pair of ensemble hand-clappersunder the influence of delay (Paper 7567)

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Introduction

The overall goal is to quantify perceived quality in interaction scenarios under the influence of delay and other factors. Here we have focused on musical interaction and have used hand clapping as an interaction scenario.
We aimed for developing a "computer hand-clapper" for semi-automated handclap experiments. This, however, required a mathematical model of behavior. To achieve this, we tried to study psychophysical effects of network latency on music as a form of human interaction.
Studying strategies taken by participants in a musical collaboration seems to be important to find out how the persons react to a delay and finally to develop a model for the behavior.

Assumptions and Methodology

- A person's behavior can change during the extent of a session.
- Strategies taken by participants in a musical interaction can be quantified by numerical parameters.

- We suggested a model and fit its parameters to an observed clapping data.
- This leaded to solving of a system of linear equations.

Compensation Factor (CF)

When a person detects that the other one has a falling tempo, then the person will have to make a decision: how early should he/she clap?
Compensation Factor, or CF, gets value of 0 when a person is clapping exactly when he/she expects the other person's clap to happen. It gets positive values when the person claps a bit earlier than he/she expects the other person's clap to be heard.
We assume that clap timings of *i* th measure for each person are given by:

$$T_i^A = T_{i-1}^B + \tau + \Delta_{i-1}^B (1 - C_i^A) \qquad (1)$$

$$T_i^B = T_{i-1}^A + \tau + \Delta_{i-1}^A (1 - C_i^B) \qquad (2)$$

$$\Delta_i^A = T_i^A - T_{i-1}^A \qquad (3)$$

$$\Delta_i^B = T_i^B - T_{i-1}^B \qquad (4)$$

We apply this system of equations, to the observed clap times detected by performing peak detection algorithms on the recording trials. Solving this system, the CF is extracted and plotted as a discrete function of time.

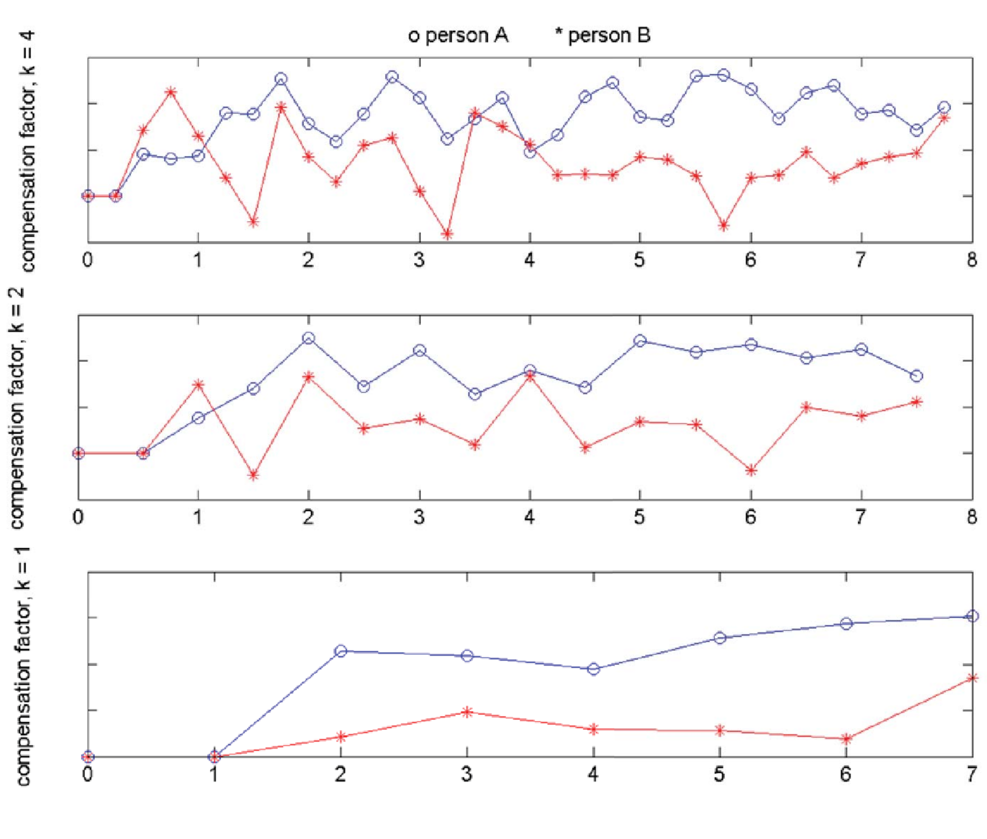

Figure 1. Compensation factors based on a recorded clapping trial for a pair of persons A (o) and B (*) with the starting given tempo of 86 bpm and the delay of 44 ms with k time stamps per clapping measure

Critical CF

What is the condition of tempo stability in a specific clapping trial?
We consider a trial with a certain delay and an assumed constant pair of CF for both sides A and B over all the measures.
We showed that after expanding equations 1 to 4, this is the condition for which the trial will have a stable tempo.:

$$C_A + C_B = 2\frac{\tau}{\Delta} \qquad (5)$$

$$C_\tau = \frac{\tau}{\Delta} \qquad (6)$$

We call the achieved "delay time over measure duration" as *critical CF*.

Hand-Clapping Experiment

The present analysis is based on further analysis of recordings that were made in a previous experiment: Pairs of subjects were set to perform simple ensemble playing by clapping rhythmical patterns with their hands, in three different acoustic conditions under an influence of delay up to 68 ms:

• real reverberant conditions (RR)
• virtual anechoic conditions (VA)
• virtual reverberant conditions (VR)

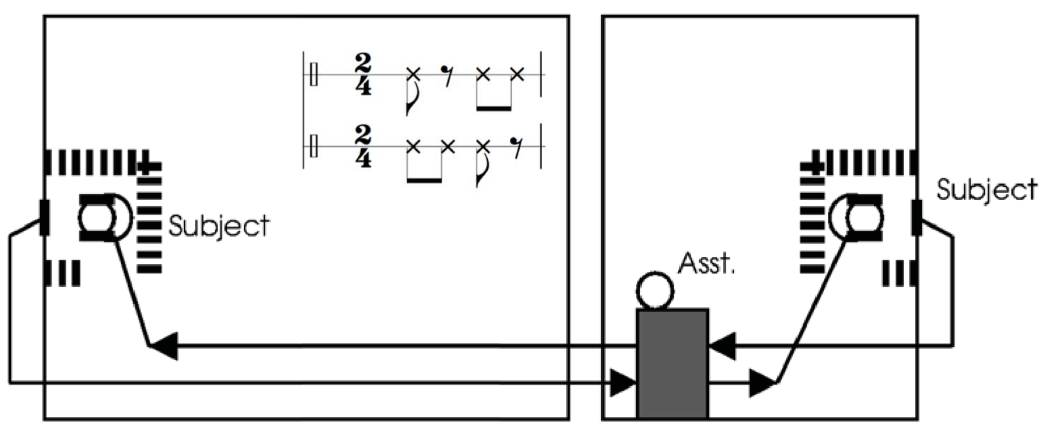

Figure 2. Subjective test used in this work as well as [1] and [2]: Subjects clapped to each other from seperated rooms while monitoring each other via headphones and microphones. The same rhythmic pattern were used.

Results

- CF increases linearly with delay:

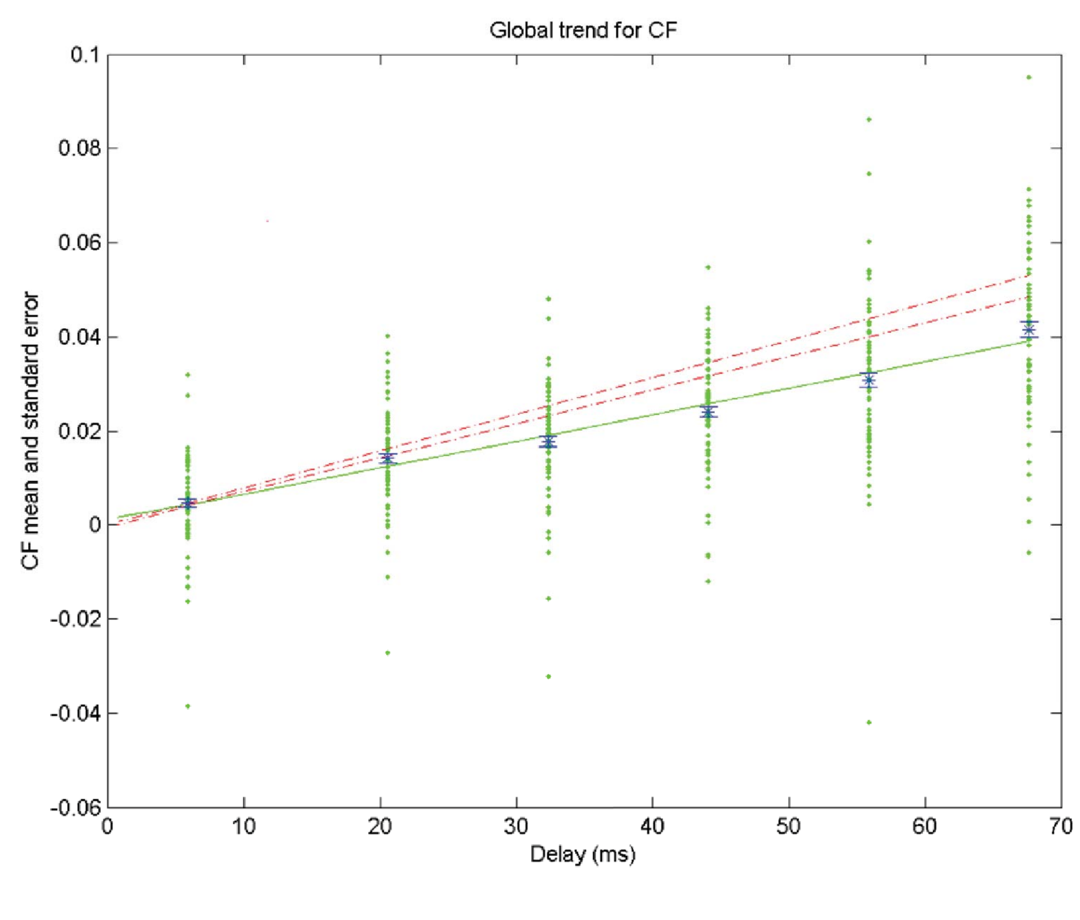

Figure 3. Global trend of CF as function of delay, fitting with *CF=1e-3*(0.5639τ+0.8391)* shows that CF increases linearly with delay. The dashed lines are critical CFs related to two our tempo limits 86 and 94 bpm.

Results

- CF can explain Chafe effect

"Chafe effect": Chafe et.al. in their hand-clapping experiment, showed that short delays (< 11.5 ms) produced a modest, but surprising acceleration. In other words moderate amounts of delay are beneficial to improve the collaboration, or tempo stability.
When there is no, or a very low, delay and a tempo increase is observed during the collaboration (while the subjects are supposed to keep the tempo constant), we are facing this effect.
Based on the data set used in present study this effect was confirmed again showing that with the delays about 15 to 23 ms the tempo increased during the sequence.

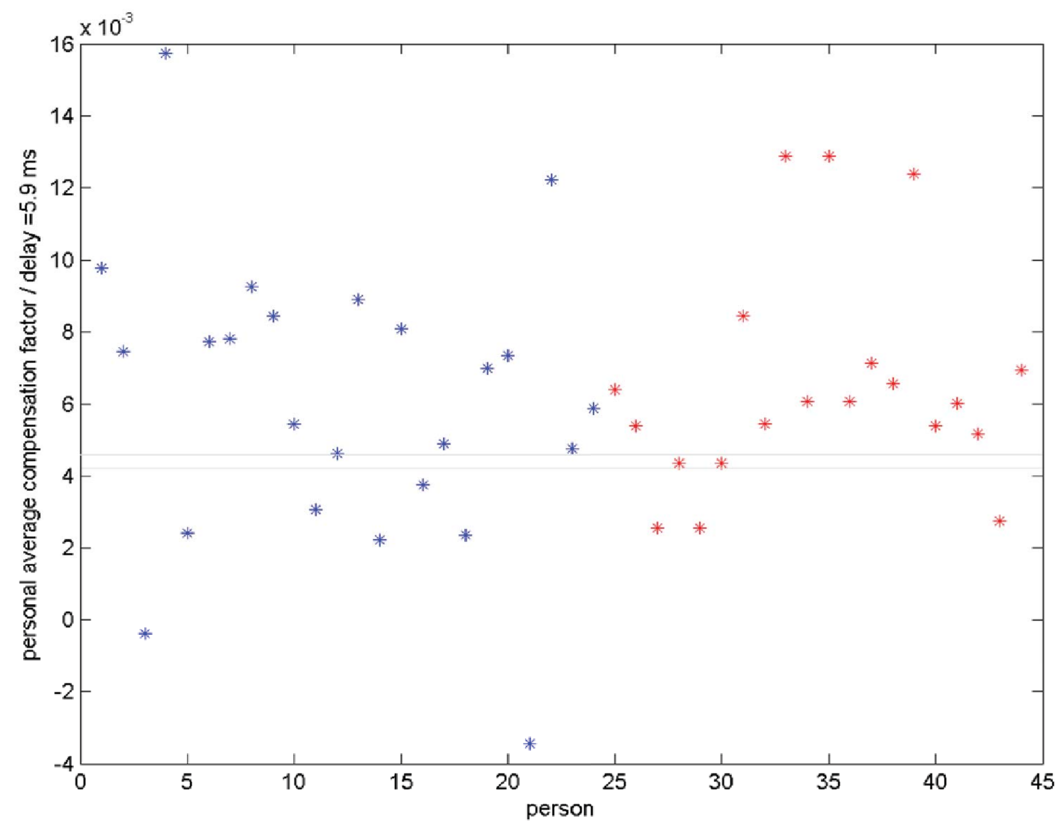

Figure 4. The CF average for each person, for the delay of 5.9 ms. The tendency to exceed critical CF for the latency of 5.9 ms showing that for such an almost non-delayed clapping session, performers are likely to speed up for compensating a suspected delay which is more than what exists.

Conclusions

- A parameter called compensation factor was suggested to capture the amount of early clapping which performers do to compensate the tempo decrease caused by latency.
- A system of equations based on the theoretical definition of theCF, was applied to the observed clap times. Solving this system, the compensation factor was extracted and plotted as a discrete function of time.
- CF was shown to be linearly increasing as a function of delay and concluded that increasing delay gives more tendencies to clap earlier, leading to a higher CF.
- We theoretically calculated a critical CF and proved that when two persons have higher CF than this boundary then the tempo will be increased and if they have less, the rhythm slows down.
- We used this definition to explain the "Chafe effect" which implies that very short latencies produce a modest acceleration.

References

[1] S. Farner, A. Solvang, A Sæbø, P. Svensson, *"Ensemble hand-clapping experiments under the influence of delay and various acoustic environments"* in Preprint no. 6905, 121th AES convention, San Francisco, CA, USA, Oct. 2006.
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[4] W. A. Sethares, *"Rhythm and Transforms"*, Springer, ISBN: 978-1846286391, July 2007.