Ensemble hand-clapping experiments under the influence of delay and various acoustic environments

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Introduction

Musical ensemble playing over the Internet has been successfully demonstrated previously [1], but is sensitive to delay, as demonstrated for hand clapping experiments by Chafe and Gurevich [2], and in a pilot study [3].

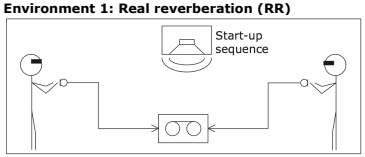
Here, we use Chafe and Gurevich' experimental setup in real and virtual acoustic environments under the influence of a delay.

Experiments

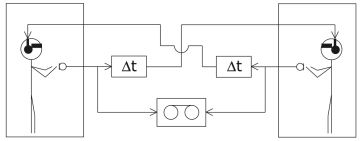
Participants were blindfolded and heard each other live (RR) or over headphones (VA and VR), see figures. Six different delays were used for each environment. Auralization, using measured binaural room impulse responses (BRIR), was used to simulate the reverberation of the RR case.

Delay [ms]	Distance [m]
5.9	2.0
20.6	7.1
32.4	11.1
44.1	15.2
55.9	19.2
67.6	23.3

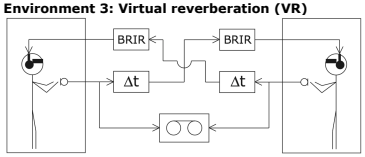
Environment 1: Real reverberation (RR)



Environment 2: Virtual anechoic (VA)



Environment 3: Virtual reverberation (VR)



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Participants and tasks

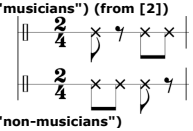
Participants with some musical training were categorized as "musicians", and others as "non-musicians". This categorization coincided with the participants' ability to perform the rhythm pattern shown under task 1 (see the paper for details).

Participants were instructed to perform together in ensemble while keeping the tempo as steady as possible. They practiced together with eye contact before the experiments. Both were given a start tempo from a recorded start-up clapping sequence. Tempos were 86, 90, and 94 bpm.

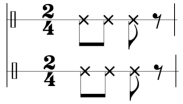
After each trial participantes were asked to grade how well the ensemble playing was accomplished: "good", "ok", "bad".

22 persons (11 pairs) participated in the RR experiment and 22 other persons participated in the VA and VR experiments.

Task 1 (for "musicians") (from [2])



Task 2 (for "non-musicians")



Signal analysis

Recordings were analyzed by extracting time instants for each hand clap by a simple peak search. Pauses were filled in with "silent time instants", so each participant got a sequence of almost equidistant time instants t_i.

Initial tempo
Calculated from the five first time instants,

$$\text{Initial tempo, } \tau_0 = \frac{1}{4}\sum_{i=0}^{3}\frac{60}{2\left(\tilde{t}_{i+1}-\tilde{t}_i\right)}$$

Tempo change
Change from first to sixth measure,

$$\text{Tempo change} = \frac{\frac{1}{4}\sum_{i=24}^{27}\frac{60}{2\left(\tilde{t}_{i+1}-\tilde{t}_i\right)}-\tau_0}{\tilde{t}_{24}-\tilde{t}_0}$$

Mean asymmetry
Mean time that subject B lags behind subject A,

$$\text{Asymmetry} = \frac{1}{N}\sum_{i=0}^{N-1}\left(t_{Bi}-t_{Ai}\right)$$

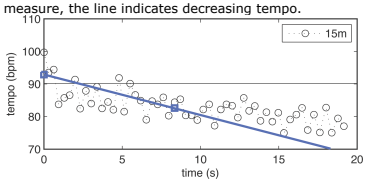
Ensemble imprecision
Standard deviation of the inter-subject differences,

$$\text{Imprecision} = \sqrt{\frac{1}{N-1}\sum_{i=0}^{N-1}\left(t_{Bi}-t_{Ai}\right)^2}$$

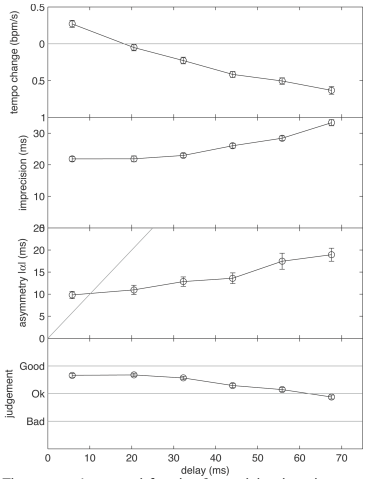
Results

Example result

The example diagram illustrates the extraction of parameters. Squares indicate tempo for the first and sixth measure, the line indicates decreasing tempo.



Global results



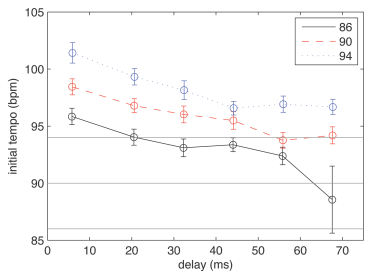
The tempo increased for the 6 ms delay but decreased for delays of 21 ms and longer.

The imprecision increased with the delay from 44 ms.

The asymmetry increased with the delay, indicating that one participant tended to take the lead for 32 ms delay and higher.

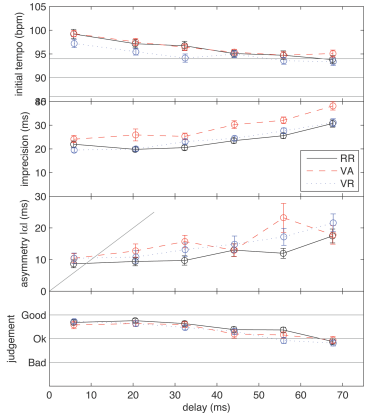
Performance was judged the same for delays up to 21 ms, slightly worse (not significant) for 32 ms, and clearly worse for delays from 44 ms.

Effect of given tempo



Surprisingly, participants used an initial tempo which was higher than the given tempo, by as much as 9%. Furthermore, the initial tempo depended on the delay, which is unexpected since the participants had barely heard each other when the initial tempo was computed (from the first measure). Participants might apparently have already been influenced by each other in the first measure.

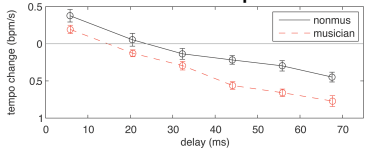
Effect of acoustic environment



Surprisingly, the initial tempo was identical in real reverberation and virtual anechoic conditions, but lower in virtual reverberant conditions. No difference in tempo decrease was found.

The imprecision, as well as asymmetry, was larger in anechoic conditions.

Effect of task/"musicianship"



The tempo decrease was more pronounced for "musicians", task 1 (complementary patterns). Zero line crossed around 15 ms for task 1 - close to Chafe and Gurevich' results (11.5 ms).

Significant differences were also observed for imprecision (higher for task 2/non-musicians), asymmetry (larger for task 2/non-musicians), and judgment (judged as worse for task 1/musicians).

Conclusions

The tempo decreased more the longer the delay was, but actually increased for low delays. For complementary rhythm patterns, a stable tempo could be expected for a delay around 15 ms (corresponding to a distance of 5 m in a room), which is close to findings by Chafe and Gurevich of 11.5 ms [2].

In general, the imprecision and performance judgment started to deteriorate from delays of 44 ms. Indications of a deterioration effect could be seen for 32 ms. This agrees with previous findings but quantifies the effects more clearly than before.

Anechoic conditions lead to a higher imprecision, and a larger asymmetry than reverberant conditions. Room reverberation thus seems to help in giving temporal cues, as expected.

Since results for anechoic conditions deviated from those for reverberant conditions, experiments that aim at representing real environments should consider these deviations.

References

[1] A.X. Xu, W. Woszczyk, Z. Settel, B. Pennycook, R. Rowe, P. Galanter, J. Bary, G. Martin, J. Corey, J.R. Cooperstock, "Real-time streaming of multichannel audio data over Internet," J. Aud. Eng. Soc. 48, pp. 627-641 [2000].

[2] C. Chafe, M. Gurevich, "Network Time Delay and Ensemble Accuracy: Effects of Latency, Asymmetry," J. Aud. Eng. Soc., [2004].

[3] H. L. Winge, "Musikksamspill over IP," Project report, Dept. of Telecommunications, NTNU, Trondheim [2003] (in Norwegian).