CAN AN OVERLY SLOW INITIAL TEMPO COUNTERACT THE DECELERATION CAUSED BY AUDITORY DELAY?

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The demands of rhythmic coordination in ensemble performance make it an ideal platform through which to study and gain insight into human interaction over the Internet, specifically in the presence of network delay. Researchers such as Chafe et al. [1] and Farner et al. [2] have conducted clapping experiments to show that below a certain delay threshold, tempo of clapping patterns tends to accelerate, and above that threshold, tempo tends to decelerate. Their experiments focused on a narrow range of initial tempi (86-94 bpm). Intuitively, initial tempo has an influence on tempo change over the course of a performance: when the initial tempo is extremely slow, performers may tend to speed up, and when the initial tempo is too fast, performers may tend to slow down. We wish to study the interaction between auditory delay and initial tempo, and their combined influence on tempo change. For example, could the acceleration caused by an overly slow initial tempo counteract the deceleration caused by auditory delay?

We first re-constructed Chafe et al.'s experiments using distance to introduce auditory delay under reverberant conditions. 18 subjects (9 pairs) clapped a simple, interlocking rhythm with delays ranging from 2 ms to 48 ms. The delay threshold we found was 6.5 ms, in contrast to Chafe et al.'s 8 ms and Farner et al.'s 15 ms.

In a second set of experiments, we expanded the range of initial tempi in order to study its effect on tempo change over the course of time. We used non-reverberant conditions (delay introduced with software) with delay levels of 2, 12, 22, 32, 42, and 52 ms and initial tempi of 52, 72, 92, 112, 132, and 152 bpm. Six clappers (3 pairs) performed the same simple, interlocking rhythm used in the first experiment, with each pair completing trials at all 36 level combinations. Interestingly, taking the average slope of the instantaneous tempo plot (a measure of tempo change) over all subjects and initial tempi, we found the amount of delay corresponding to zero tempo change to be approximately 7.87 ms, very similar to Chafe et al.'s result of 8 ms.

We found that the initial tempo had a strong effect on tempo change through a performance. There was little change in tempo when the intial tempo was 72 or 92 bpm. At these tempi, the optimal delay (that which corresponds to zero tempo change) was about 20 ms. This value was estimated by finding the x-intercept of the linear fit to tempo change as a function of delay. At 52 bpm, there was a strong tendency to accelerate; correspondingly the optimal delay increased to 43 ms, showing that the tendency to accelerate due to slow initial tempo counteracted the tendency to decelerate due to increasing delay levels. At tempi of 112 and above, there was a strong tendency to decelerate; at 152 bpm, the optimal delay was pushed to -15 ms.

However, in the context of coordinating a remote performance, it is unnatural to think of the optimal delay as the independent variable. Instead, we can re-analyze the results to find the optimal tempo at each delay. At a delay of 2 ms, where there is a tendency to accelerate, the optimal tempo (that which corresponds to zero tempo change) is 82 bpm. This value was estimated by finding the x-intercept of the linear fit to tempo change as a function of initial tempo. At a delay of 52 ms, where there is a strong tendency to decelerate, the optimal tempo is reduced to 42 bpm. By averaging the slope of the instantaneous tempo plot for all subjects across all amounts of delay, we found that the optimal initial tempo, at any delay, is approximately 74.5 bpm. It is worth noting that this tempo is well within the human heart rate range of 60-80 bpm (American Heart Association).

These results were obtained with relatively few subjects, and so while the trends are clear, the error associated with many of these observations is high. The actual optimal values could be more precisely measured in a larger scale study.

To summarize, tempo change over the course of a rhythmic performance was found to depend on initial tempo as well as auditory delay. Moreover, it seems that the values of these parameters can be set deliberately in order to minimize tempo change. For instance, performers could plan, in the presence of a known network delay, to rehearse at an overly slow tempo. The acceleration in response to the slow tempo could counteract the deceleration due to network delay, resulting in little to no tempo change. This raises the possibility of a third performance pressure: that of wanting to revert to a practiced tempo. To fully understand these possibilities, this research should be validated by testing performer's tempo changes in the presence of delay when performing rehearsed pieces of music.

ACKNOWLEDGEMENTS

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