The Influence of Rhythmic Tempo on Sustained Entrainment to the Beat

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1. BACKGROUND AND AIMS [Catherine Jameson]

1.1 Introduction

Our research question stems from an interest in the continuation of entrainment, a neurological process by which the brain selectively attends to moments it expects to hear a beat. This is particularly important between movements in classical music or tracks on an album. We wanted to understand how entrainment affects the silence in these transitions, when musicians want to keep the audience captivated while avoiding a jarring transition.

1.2 Previous Research

Chen, Repp, & Patel (2002) measured a very similar effect, except instead of silence, gave participants sounds that matched their tapping, and compared visual to aural stimulus. They found two sources of errors, one over shorter intervals of time after the stimulus stopped being regular, and one which extended longer and resulted in a slow shift of tempo. Fredrickson (1994) also measured the ability to maintain a steady pulse when cues were taken away, this time in band musicians. Some musicians lost aural cues (of the rest of the band playing), and some lost visual cues (a video of the conductor) partway through a piece they were reading. In general, the musicians sped up, especially at the loss of aural cues, and it was determined by tracking eye motion that eye contact with the conductor was essential for success.

Repp & Su (in press) summarize the current state of synchronization studies, which measure the asynchronies of subjects tapping along with isochronous beats. Their discussion of the importance of different IOI as an important variable informs our decision to test many tempi as our independent variable.

Finally, neurological studies, though a different experimental design than our behavioural study, offer insight into underlying brain structures which contribute to entrainment. Grahn (2009) summarizes the conclusions of several music neuroscience studies and relates that the areas most related to timing are also those often associated with movement. These include the cerebellum, basal ganglia, parietal cortex, premotor cortex, and supplementary motor area. Jomori, Uemura, Nakagawa, and Hoshiyama (2011) use event related potentials to investigate areas of the brain associated with imagining a beat. In their design, 4 pulses were followed by 5 seconds of silence. They found that the left frontal lobe had the most activity.

1.3 Present Research

When we have been entrained to a meter, for how long after the beat stops can we maintain that entrainment? How is this ability to extend entrainment into silence affected by different tempi?

2. METHOD [Robert Strebendt]

Participants are told that in each trial they will hear a metronome beat, to which they should immediately begin synchronizing their taps (by clicking their mouse). Participants are informed that at some point the metronome will cut out (so that all they will hear is silence), but that, nevertheless, they should continue tapping at the same rate the metronome had been playing at. After 20 seconds of silence, a high pitched beep will occur signifying the end of the trial.

For a given trial, participants always hear 24 beats of a metronome, followed by a 20 second silence. There are 7 different tempo conditions–IOIs from 300ms to 1825ms, ascending in steps of 175ms with ± 0-25ms to the resulting

IOIs to avoid metric relationships between the different tempo conditions. All rhythms are created in Finale, edited in Audacity and then recorded as .mp3 files, to be played during the experiment. Before taking part in the experiment proper, participants complete a survey on their musical background followed by a trial where participants are prompted to tap any consistent tempo while no auditory stimuli is present.

2.1 Participants

Our subject pool consists of 10 people ages 19-39. 7 are female and 3 are male. All have at least some college education and an average of 11 years of musical training on their principal instrument (with a range of 1 to 20 years and a standard deviation of 6 years). Four also played another instrument, averaging 5.3 years of experience (with a range from 1 to 8 years and a standard deviation of 2.7 years). Each person also listens to avant garde music, classical music, or both, and most also listen to pop (rock/rap/hip-hop). They speak a variety of languages, but their first languages are primarily English, with one French and one Spanish. None of the subjects have perfect pitch.

2.2 Stimuli

The seven different tempo conditions were created using Finale to gerate a synthesized woodblock timbre and tempo, then exporting the sound files to Audacity to edit the durations and check for accuracy. The seven tempo conditions were 300ms, 480ms, 625ms, 750ms, 1000ms, 1200ms, and 1875ms.

2.3 Task & Procedure

Participants proceed through 3 blocks of 7 trials each for a total of 21 trials. Each trial consists of 24 beats of the tempo stimulus, followed by 20 seconds of silence which they are to continue tapping the given tempo through. Participants The order of trials is fully randomized per participant, and there are never two trials of the same condition played consecutively.

2.4 Data Collection

Participant data was accumulated on the client side and sent to the master server upon completion of the study. The online study recorded discrete input signals from the participants ITIs (ie. clicking) in the form of milliseconds. The resulting raw data listed a string of accumulative increasing ITIs per participants trial.

3. RESULTS & DISCUSSION

3.1 Main Findings [Julian DeFrietas]

We excluded one subject for not having completed the experiment. We also excluded all responses falling 2.5 standard deviations either above or below the subject's mean response. Percentage errors were calculated by taking the absolute value of the differences between response times and the conditional IOIs for both the listening and silencing periods (we used both to increase our statistical power), and dividing this answer by the respective IOIs. All subsequent data analysis was done using the R Statistical programming language (R Core Team, 2013). Although figure 1 suggests a weak trend whereby extreme IOIs were more disruptive to sustained synchronization in the absence of the beat (or whereby retention of tempo in the 480-750ms IOI range was more robust), a one-way ANOVA revealed that percentage errors did not differ significantly across IOI conditions, $F(6,63) = 0.74, 0.62$. More data may be needed to investigate whether any real differences exist.

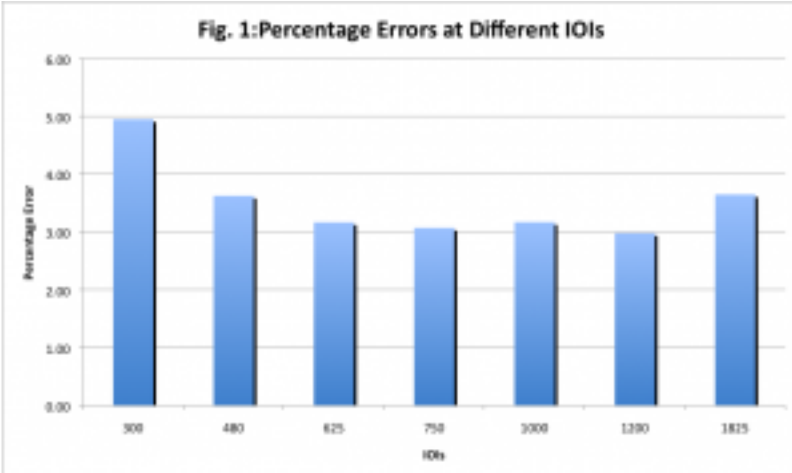


Fig. 1:Percentage Errors at Different IOIs

The distribution of responses can be seen in figure 2, and a one way ANOVA confirmed that no significant differences existed among standard deviations of responses at the different IOIs, $F(6,63) = 0.857$, 0.531.

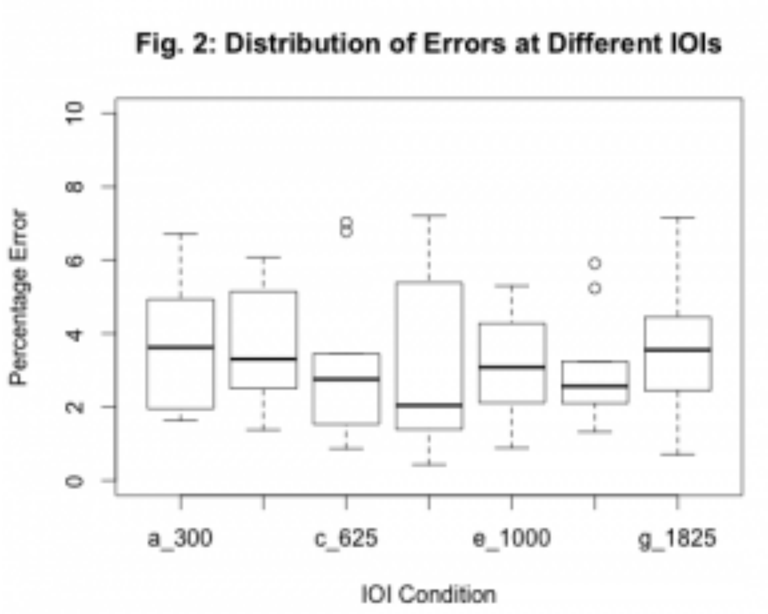


Fig. 2: Distribution of Errors at Different IOIs

We also made an exploratory plot of percentage errors for the first vs. second half of subject's responses (figure 3), and interestingly these suggest that much of the trend seen in figure 1 may have actually been driven by subject's responses during the listening period. Therefore, it is possible that even fewer differences than originally anticipated exist for ITIs in the absence of the beat, although more data is needed to say this conclusively.

Fig. 3: Percentage Errors for 1st vs. 2nd Half of Responses

Figure 5 shows a medium correlation between confidence ratings (figure 4) and percentage errors, whereby IOI conditions with low error rates seemed to produce the highest confidence ratings, suggesting that overall these IOIs were easier to tap out, R^2 = 0.451. However, a one way ANOVA showed no significant differences among confidence ratings, F(6,63) = 0.531, 0.782, and the correlation may be even weaker when only responses during the silence are analyzed.

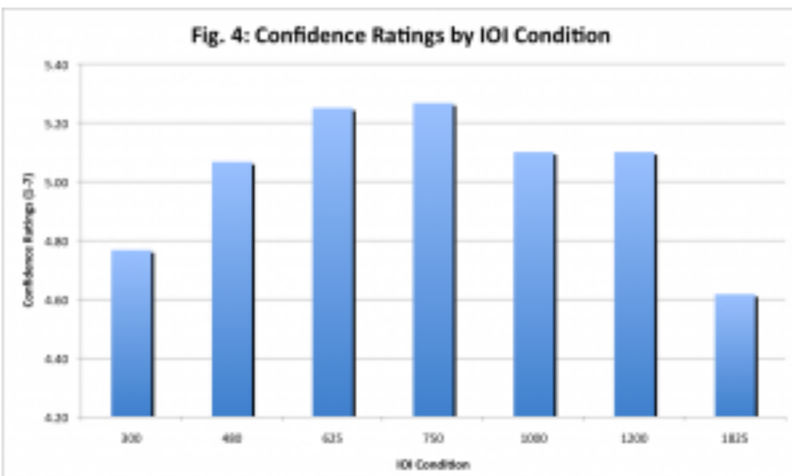


Fig. 4: Confidence Ratings by IOI Condition

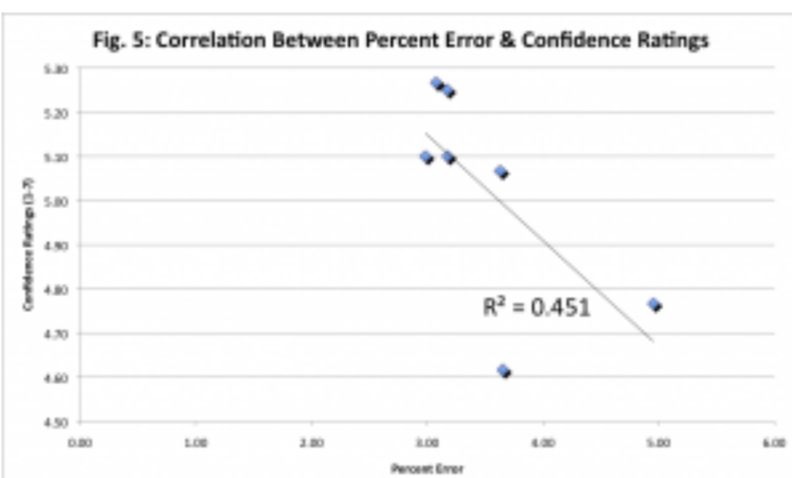
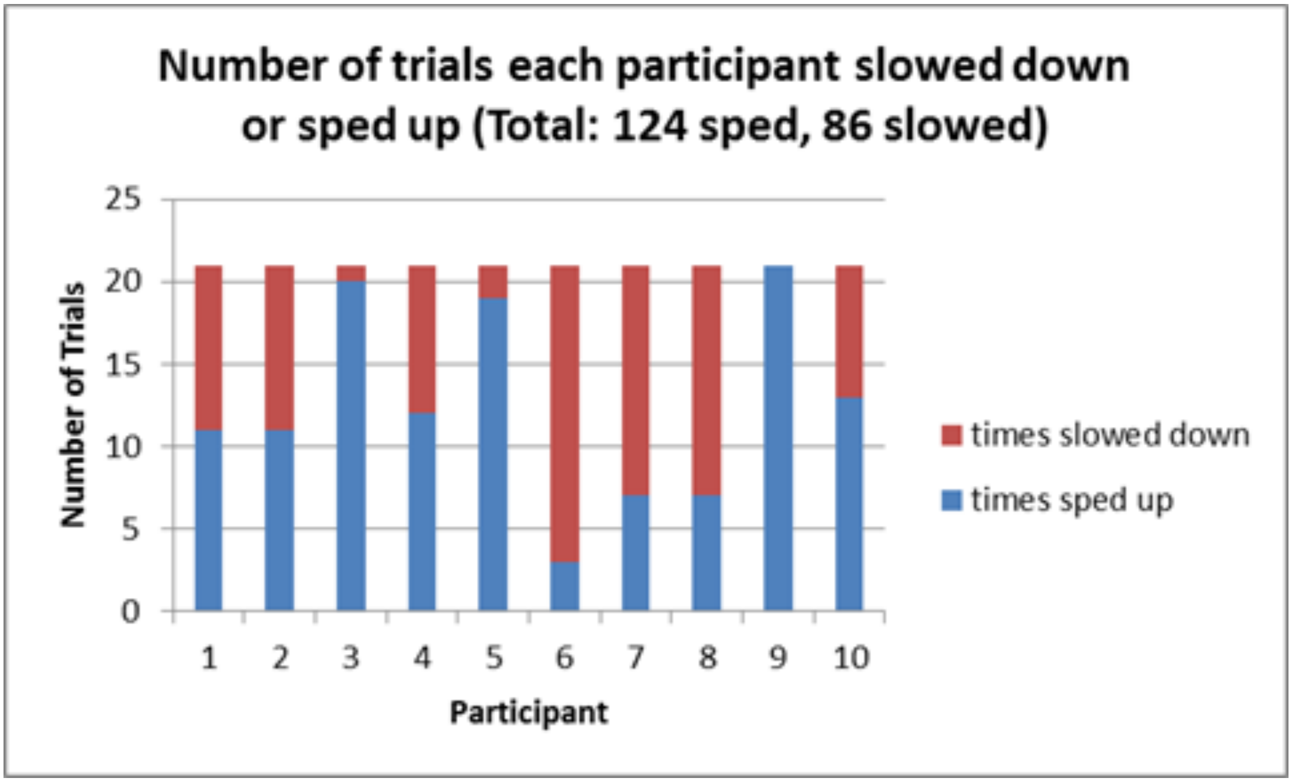


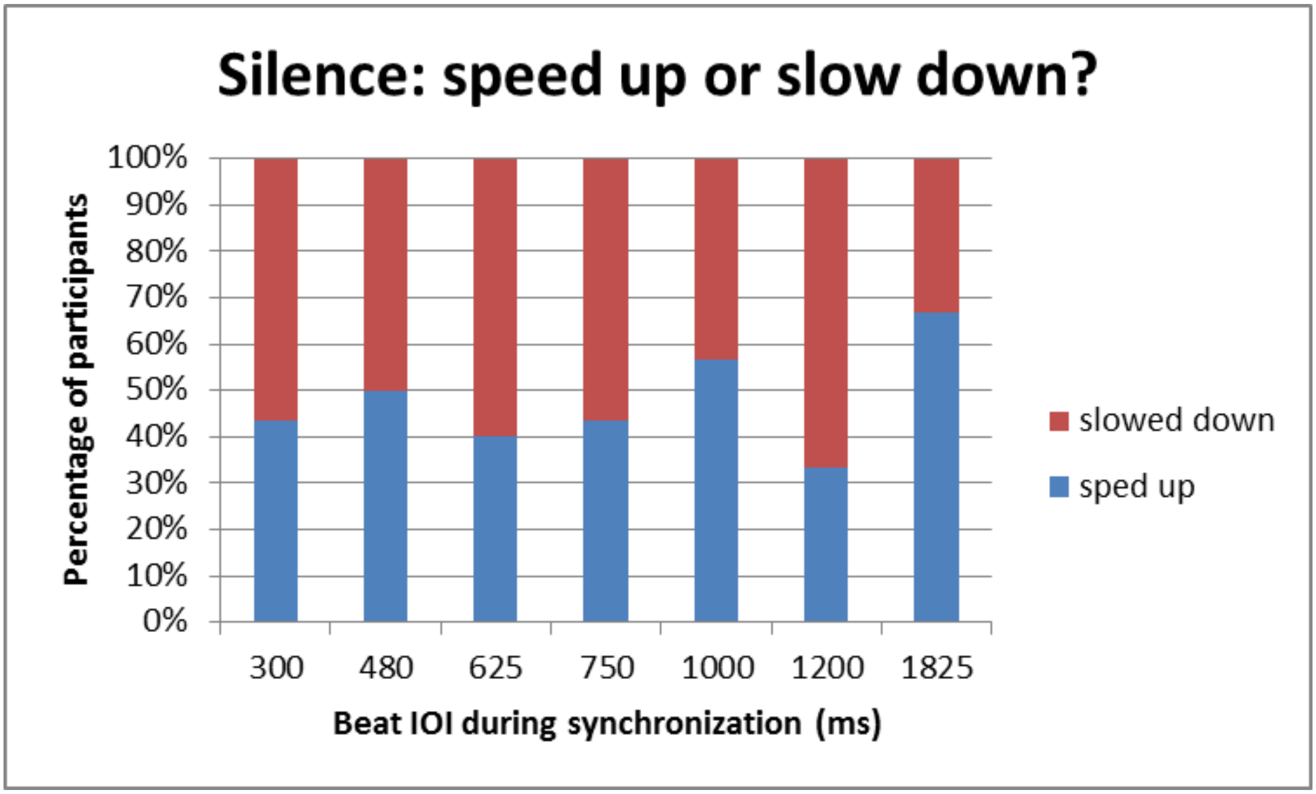
Fig. 5: Correlation Between Percent Error & Confidence Ratings

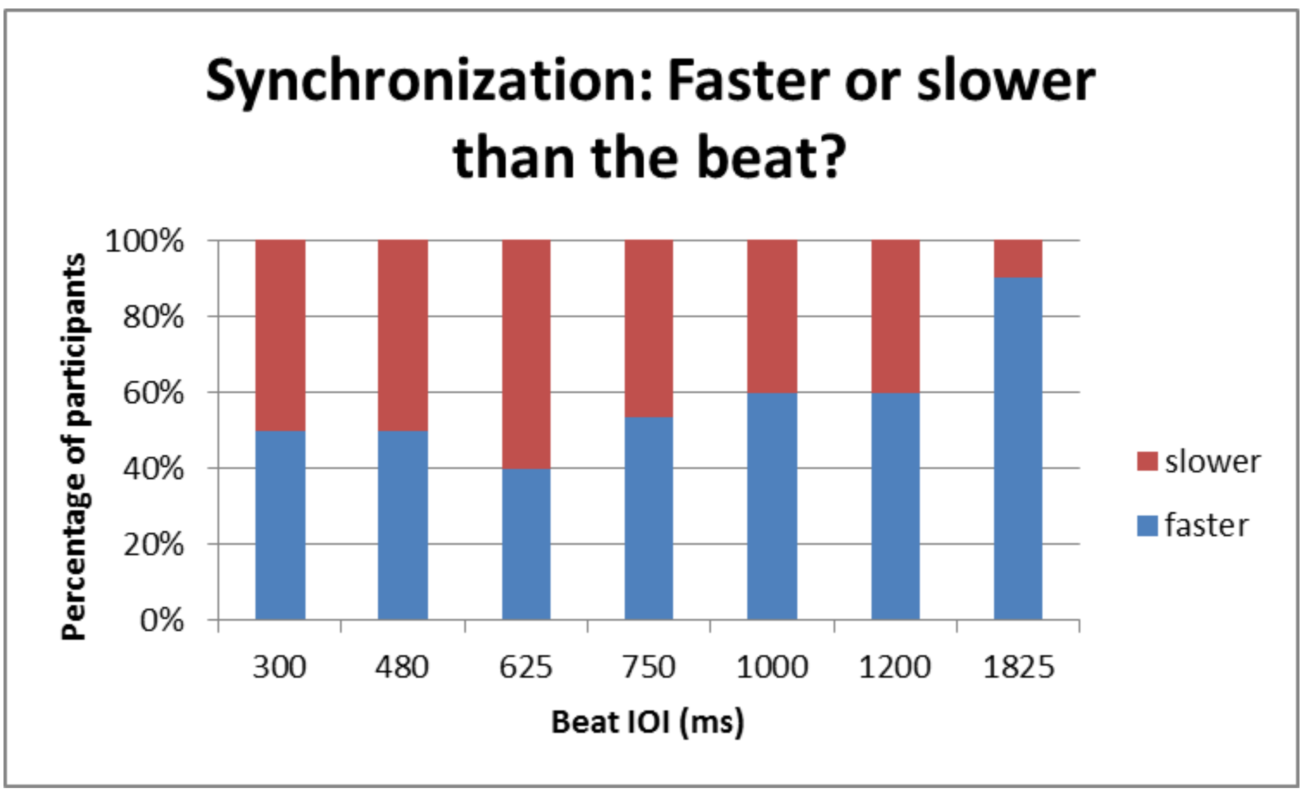
3.2 Speeding up or slowing down? [Catherine Jameson]

In this analysis, we looked at subjects' tendencies towards either speeding up or slowing down by comparing average ITI over various intervals with the IOI of the stimulus beat. Comparing participants, some tended to always run faster than the IOI, some always slower, and most fell in between. For the following figure, average ITI across the entire trial (synchronization and silence) was analysed.



In order to examine a confound between synchronization and silence conditions, I then compared average ITIs during each condition at each IOI with the stimulus beat. In the figure representing the silence condition, these seem fairly well distributed around 50% (range 33% to 67%), with no upwards or downwards trend. In the synchronization condition, however, there is a slight upwards trend. This is curious, as a participant would need to add extra beats in order to register a higher ITI than the beat IOI, but the person was listening during this phase. It is possible some people felt the tempo was so slow in the 1825ms condition that they decided to subdivide, double tapping, or that they self-corrected an early tap by re-tapping at the actual beat time, thereby adding extra taps.


Silence: speed up or slow down?
Percentage of participants
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
300
480
625
750
1000
1200
1825
Beat IOI during synchronization (ms)
slowed down
sped up


Synchronization: Faster or slower than the beat?
Percentage of participants
100%
80%
60%
40%
20%
0%
300
480
625
750
1000
1200
1825
Beat IOI (ms)
slower
faster

Furthermore, I examined whether the direction of asynchrony corresponded with a tendency towards each subject's spontaneous tapping rate. This trial was done first, before any stimulus had been heard, and measured each subject's comfortable, natural tapping ITI. We found that 27.5% of the time, participants tapped at a rate between their spontaneous rate and the beat IOI rate of that trial. This was true of 52 trials (out of 189 trials we counted for this part), which gives a standard deviation of 7.2 for the times it was true and 11.7 for the times this condition was not satisfied. The average spontaneous tapping rate was 747.5ms, with a SD of 215ms. Only 8 participants correctly did this task (3 were thrown off and only tapped a couple of times), so there were fewer data points on this than for other data comparisons. Though we hypothesized that subject's ITIs might converge on their spontaneous tapping rate, this is not the case. In fact, they tended away from their spontaneous rate. Perhaps subjects realized that a beat was "very fast" or "very slow" and exaggerated their response in the silence condition, speeding through fast trials and drawing out slower ones.

4. GENERAL DISCUSSION [Julian De Freitas]

It is known from previous research that some tempi are easier to entrain to than others. Here we investigated whether these differences extend to tapping in the absence of the beat. All analyses suggested "no", although plotting the results suggested the possibility of at least a weak trend whereby the quickest IOIs disrupted synchronization more. Furthermore, subjects may have been at least a little less confident in their responses when responding to extreme IOIs.

Given the limited number of subjects, it is hard to interpret these data conclusively, although the lack of a clear trend is somewhat ominous for hypotheses predicting differences among different IOIs (at least for the IOI range used in this study). With more statistical power, we would break down our analyses into different windows, for example, comparing the first 10 seconds of silence to the last 10 seconds. A greater subject sample would also allow for a more detailed investigation of the direction of errors: on average, were subjects under or over-estimating imagined beat onsets, and did this trend change over time?

Aside from including more subjects, the current study could be improved by including an additional experiment in which the amount of exposure time to the different tempi is controlled across the different IOIs: we currently controlled for the number of beats to which subjects were exposed, but this consequently led to longer exposure times to some IOIs, which may have driven the current results. We would want to ensure that the same results are obtained when exposure time to the different beat IOIs is controlled. Another concern is that the current design does not feature sufficiently different tempi to highlight differences in sustained tapping in the absence of the beat. Future studies could feature a wider range of IOIs, in order to more thoroughly explore whether any differences in ITIs may exist.

Finally, the current design was not the cleanest test of tapping in the absence of the beat, since it is possible that subject's synchronized to the sound of their own clicking. Had we controlled for this factor (for example, by using a silent taping pad), it is possible that subjects would have desynchronized from the initially heard beat more quickly, thereby better highlighting any differences that could exist for the different conditions. Along these lines, a longer silence period may have also done a better job at teasing out any differences. For now, we conclude that, although our results remain inconclusive, we find no clear evidence for an influence of different tempi on sustained tapping in the absence of the beat.

REFERENCES

R Core Team. (2013). A language and environment for statistical computing. *R Foundation for Statistical Computing*. Vienna, Austria.