The Effect of Exercise-Induced Arousal on Chosen Tempi for Familiar Melodies

Kelly Jakubowski (corresponding author)
Department of Psychology, Goldsmiths, University of London
New Cross Road, New Cross
London SE14 6NW
Telephone: +44-75-3003-5647
email: k.jakubowski@gold.ac.uk

Andrea R. Halpern
Bucknell University, USA

Mick Grierson
Goldsmiths, University of London

Lauren Stewart
Goldsmiths, University of London

Author Note: This study was funded by a grant from the Leverhulme Trust, reference RPG-297, awarded to author LS.

Abstract

Many previous studies have shown that arousal affects time perception, suggesting a direct influence of arousal on the speed of the pacemaker of the internal clock. However, it is unknown whether arousal influences the mental representation of tempo (speed) for highly familiar and complex stimuli, such as well-known melodies, that have long-term representations in memory. Previous research suggests that mental representations of the tempo of familiar melodies are stable over time; the present study aimed to investigate whether these representations can be systematically altered via an increase in physiological arousal. Participants adjusted the tempo of 14 familiar melodies in real time, until they found a tempo that matched their internal representation of the appropriate tempo for that piece. The task was carried out before and after a physiologically arousing (exercise) or non-arousing (anagrams) manipulation. Participants completed this task both while hearing the melodies aloud and while imagining them. Chosen tempi increased significantly following exercise-induced arousal, regardless of whether a melody was heard aloud or imagined. These findings suggest that a change in internal clock speed affects temporal judgments even for highly familiar and complex stimuli such as music.

Keywords: musical tempo, time perception, musical imagery

The Effect of Exercise-Induced Arousal on Chosen Tempi for Familiar Melodies

Human time perception is influenced by diverse psychological factors, ranging from age to clinical disorders to psychoactive drugs (e.g., Pastor, Artieda, Jahanshahi, & Obeso, 1992; Salthouse, 1996; Wittmann, Leland, Churan, & Paulus, 2007). One such factor that naturally varies is physiological arousal. In previous studies of time perception, arousal has been manipulated via stress (Boltz, 1994), physical activity (Schwarz, Winkler, & Sedlmeier, 2013), fear (Grommet, Droit-Volet, Gil, Hemmes, Baker, & Brown, 2011), or fatigue (Miró, Cano, Espinosa-Fernández, & Buela-Casal, 2003). Increased levels of physiological arousal led to longer duration estimates for retrospective judgments of the length of visual or auditory stimuli (Grommet et al., 2011; Wearden, Pilkington, & Carter, 1999) and underestimations in time production tasks (Miró et al., 2003; Ozel, Larue, & Dosseville, 2004).

These and similar findings have often been explained within the context of pacemaker-accumulator models (Church, 1984; Gibbon, 1991). Such models implicate an internal clock comprising a pacemaker responsible for emitting pulses at a certain rate, a switch that opens when a period requiring a time judgment begins, and an accumulator that holds the pulses emitted during the period. Several later adaptations of these models (e.g., Zakay & Block, 1996) add an attention component in which an attentional gate opens more fully between the pacemaker and accumulator as attention is allocated to a timing task. Thus more pulses accumulate when time is seen as important and relevant, while some pulses may be lost if attentional resources are allocated elsewhere.

Previous researchers have posited that the rate of pulse emission within the pacemaker increases with heightened physiological arousal (e.g., Boltz, 1994; Wearden et al., 1999). An increase in the speed of the pacemaker leads to the collection of more pulses in a shorter duration of time within the accumulator. This causes retrospective time judgments to be overestimated, as less time is required for more pulses to accumulate. In prospective time judgment tasks—e.g., if a participant is asked to respond when 10 seconds have passed – arousal can lead to underestimations of time, as the accumulator's store reaches a certain number of pulses at a faster rate than under normal conditions.

The aforementioned studies suggest converging evidence for the influence of physiological arousal on time perception for both visual and auditory stimuli. However, several important questions about the generality of these effects remain. The tasks employed by previous researchers frequently required duration judgments for experimenter-constructed, single events (e.g., Grommet et al., 2011; Schwarz, et al., 2013), which may not generalize to the types of complex temporal judgments often made in everyday life. Previous studies have also often required a training phase (e.g., Boltz, 1994), which can introduce confounds due to individual differences in ability to learn and retain unfamiliar stimuli. The present study aimed to utilize a more ecologically valid task and eliminate the need for a training phase by using stimuli already highly familiar to participants.

Previous research has shown that the tempo of familiar melodies is recalled highly accurately for songs that exist in a definitive recorded version (Levitin & Cook, 1996) and consistently for those that have no standard version, such as "Happy Birthday" (Halpern, 1988). Levitin and Cook (1996) asked participants to sing familiar pop songs from memory and found that a significant proportion of the sample came within the boundaries of the perceptual threshold (JND) for tempo. Halpern (1988) asked participants to adjust the speed of a metronome to the tempo that sounded "correct" for 19 different well-known songs. They completed this task both while hearing the songs aloud and while imagining them in their heads. A significant correlation was found between the preferred perceived and imagined tempi of the songs, indicating that participants were quite consistent at setting the tempo of the songs regardless of whether they were being heard aloud or imagined. Halpern's study suggests a type of absolute memory for tempo of songs, even for those without a standard recorded version.

Some previous evidence suggests that mental representations of music and other temporally regular sequences may be affected by changes to the internal clock speed. Iwanaga (1995) asked participants to adjust the speed of "It's a Small World" to their favorite tempo and found that participants' preferred tempi were close to speed of their heart rates. However, the use of only one song stimulus, rather than a range of songs with different original tempi, imposes some limitations regarding the generalizability of these findings. North and Hargreaves (2000) found that participants preferred and listened longer to a faster tempo piece of music in an exercise condition as compared to a relaxation condition. Additionally, Boltz (1994) found a significant increase in post-manipulation spontaneous tapping speed in participants assigned to a stress-inducing condition, and a significant decrease in tapping speed in a relaxation group.

In the present study, a task was designed with parallels to a familiar everyday situation: choosing the speed for singing or imagining a well-known song, such as "Happy Birthday" or "Jingle Bells." We investigated whether one's generally stable tempo representations for familiar melodies could be systematically altered by an increase in physiological arousal. Arousal was induced via aerobic exercise (jogging in place). Participants' choices of tempi for 14 familiar songs were measured before and after exercise by asking them to adjust the speed of each song in real time until the tempo of the song sounded "right" to them. This is in contrast to such studies as Hargreaves and North (2000), in which participants provided liking ratings as well as appropriateness ratings within a given context, as we aimed rather to investigate the tempo that felt internally “correct” to each participant. These chosen tempi were compared to chosen tempi of a control group who completed a mentally-- rather than physically-- demanding task (anagrams). To investigate the potential influence of individual differences in musical training and self-reported auditory imagery abilities on chosen tempi, questionnaires were administered to assess these factors. Our main hypothesis was that an increase in physiological arousal induced by exercise would increase participants’ chosen tempi; participants in the anagram group, for whom no change in physiological arousal was anticipated, were predicted to show no change in chosen tempi. This result would provide robust evidence for the influence of arousal on the speed of the internal clock by showing that even the chosen tempo of a complex stimulus such as familiar music, which has stable representations in memory, can be altered via changes in physiological arousal.

As in Halpern (1988), we compared chosen tempi for both perceived and imagined familiar songs. The experience of imagined music-- termed musical imagery-- preserves many fundamental elements of musical structure, including pitch, tempo, and timbre (see Hubbard, 2010 for a review) and similar brain regions are recruited in perceiving a melody aloud versus purely imagining it (see Zatorre & Halpern, 2005 for a review). As such, we hypothesized that chosen tempi for perceived and imagined songs would be similarly affected by an increase in physiological arousal.

Method

Design

The study utilized a 2x2 mixed design. A between-subjects factor of manipulation (exercise vs. anagrams) was employed to increase physiological arousal via increase in heart rate in the exercise group and to maintain a constant state of physiological arousal in the anagram group. The within-subjects factor was task type (music perception vs. musical imagery).

Participants

A total of 39 participants (15 male) took part, ranging in age from 19-34 years (M = 23, SD = 4.1). Twenty participants were assigned to the exercise group and 19 were assigned to the anagram group.

Participants were asked to confirm that they were familiar with all 14 songs used as stimuli and that they were able to participate in 8 minutes of moderate aerobic exercise. All participants received course credit or payment of £10.

Materials

Musical stimuli for both the perceived and imagined music conditions consisted of 14 well-known songs (see Table 1), based on those used by Halpern (1988). These songs were very familiar to the participants but do not exist in any one definitive version (i.e., most people do not listen to a specific recorded version of “Happy Birthday”). The first musical phrase of each song was extracted for use and these excerpts were recorded in MIDI piano timbre. The recorded tempo for each song was determined by averaging the chosen tempi of four independent judges in a pilot study. All songs were then presented at either a fast or slow start tempo (50% or 175% of the recorded speed) to ensure that participants would make tempo adjustments for all or most of the songs.

In order for participants to adjust the speed of the musical stimuli, a Max/MSP application was designed for making tempo adjustments in real time. The application allowed a participant to increase or decrease the speed of a song as it was being heard, without any changes in sound quality (pitch, loudness, etc.), via a Griffin Powermate assignable USB controller. The Powermate is a circular dial that can make continuous adjustments in very small increments but that has no external calibration marks. This controller thus reduces the possibility of remembering the position at which the last trial was set.

For the between-subjects manipulation (exercise vs. anagrams), heart rate measurements were used as an indicator of physiological arousal. An Ultrasport Pulsewatch Run50 heart rate monitor with chest strap was used to measure participants' heart rates in both the exercise and anagram groups.

Finally, we examined individual differences in music-related abilities. The musical training dimension of the Goldsmiths Musical Sophistication Index (Gold-MSI; Müllensiefen, Gingras, Stewart, & Musil, 2011) was administered to measure formal musical training. This scale includes questions relating to prior music lessons and practice, music theory training, and performance experience. The Bucknell Auditory Imagery Scale (BAIS) was administered to measure self-reported auditory imagery abilities. The BAIS is divided into two subscales- vividness and control. It measures participants' auditory imagery abilities for musical, speech, and environmental sounds in terms of how vividly they are able to voluntarily imagine these sounds (vividness subscale) and how easily they are able to control and change these imagined sounds (control subscale).

Procedure

Each participant completed four blocks of 14 trials each (see Figure 1). The 14 songs were presented in four different random orders, which were counterbalanced across participants. Each testing session lasted approximately 75 minutes.

BLOCK 1	**BLOCK 2**	**BLOCK 3**	**BLOCK 4**
14 trials perception task	-60 s jogging OR anagrams -3 trials perception task -60 s jogging OR anagrams -4 trials perception task -60 s jogging OR anagrams -3 trials perception task -60 s jogging OR anagrams -4 trials perception task	14 trials imagery task	-60 s jogging OR anagrams -3 trials imagery task -60 s jogging OR anagrams -4 trials imagery task -60 s jogging OR anagrams -3 trials imagery task -60 s jogging OR anagrams -4 trials imagery task

Figure 1. Procedural layout for Blocks 1-4.

The first block each participant completed was a perception task.[1] For each trial, participants saw the printed name and first line of lyrics to one of the 14 songs. They subsequently heard the music corresponding to the written line of the song and were asked to "please adjust the knob until the speed of the music sounds right to you." The start tempo for each trial was set to either 50% or 175% of the speed of the original recorded sound file (see Table 1 for a list of recorded and start tempi).

[1]All participants began with the perception tasks and then proceeded to the imagery tasks. This is due to the fact that the perception task provides an actual, perceived experience of each of the 14 songs, thereby priming participants to be able recall the music purely in their heads during the imagery task. In pilot testing, counterbalancing of perception and imagery was attempted and some participants who completed the imagery task before the perception stated that they experienced difficulty recalling the songs because it had been a long time since they had heard them aloud.

Table 1

14 Songs Used as Stimuli in Perception and Imagery Tasks

Song	Recorded tempo (bpm)	Fast start tempo for perception task (bpm)	Slow start tempo for perception task (bpm)
Deck the Hall	69	120.75	34.5
Happy Birthday	128	224	64
Hark the Herald Angels Sing	56	98	28
Jingle Bells	100	175	50
London Bridge	81.5	142.625	40.75
Old MacDonald Had a Farm	75	131.25	37.5
Row, Row, Row Your Boat	104	182	52
Rudolph the Red-Nosed Reindeer	75	131.25	37.5
Santa Claus is Coming to Town	132	231	66
Silent Night	112	196	56
Three Blind Mice	112	196	56
Twinkle, Twinkle Little Star	75	131.25	37.5
When the Saints Go Marching In	112	196	56
White Christmas	75	131.25	37.5

Note: Fast start tempi are 175% of the speed of the original recorded tempo and slow start tempi are 50% of the original recorded tempo. The click track for the imagery task was started at a tempo of either 48 bpm or 204 bpm. For any individual participant, a given song was always presented at either a slow start speed or a fast start speed for all 4 blocks. This was done to account for possible response biases toward the initial presented tempo of the song or click track, which could potentially minimize effects owing to the experimental manipulation.

In the second block, participants completed four 60 s periods of the between-subjects manipulation (either exercise or anagrams), each of which was interspersed with the perception task. The manipulation was administered in this interspersed format in an effort to deter heart rate from returning too quickly to baseline in the exercise group throughout the 14 tempo adjustment trials. During the manipulation periods, the exercise participants jogged in place, whereas the anagram participants completed as many anagrams on a worksheet as they were able during the 60 s period. The experimenter watched the heart rate monitor during each jogging period to ensure the exercise group participants were within the range of 50-70% of their maximum heart rate (maximum HR was calculated as 220-age). This range was based on procedures from previous behavioral studies utilizing aerobic exercise in a similar fashion (Murray & Russoniello 2012; Pontifex & Hillman, 2007). The experimenter asked participants to increase or decrease their jogging speed if needed, within their ability. All participants were able to exercise within this target range for the 60 s periods.

Following the second block, participants filled out the Gold-MSI and BAIS questionnaires. This phase ensured that the exercise participants' heart rates returned to baseline before beginning the third block. There was no significant difference between exercise participants' baseline heart rates prior to commencing the experiment and their heart rates after the questionnaire period, $t\ (19) = 1.36$, $p = 0.19$.

In the third block, participants completed an imagery task. This task was analogous to the perception task from Block 1, with the only difference being that participants were asked to indicate the tempi at which the same set of 14 songs sounded correct while *imagining* (rather than hearing) them. Participants heard a click track and were asked to align the clicks to the beat of the imagined music. The text of the corresponding lyrics of the song was marked in bold and underlined wherever the beat corresponded with a word/syllable, in order to aid participants in discerning how to align the clicks with their mental imagery (see Figure 2). The fourth block combined the manipulation with the imagery task in the same interspersed format as employed with the perception task in Block 2.

LONDON BRIDGE

<u>Lon</u>don **<u>Bridge</u>** is **<u>fall</u>**ing **<u>down</u>**, **<u>fall</u>**ing **<u>down</u>**, **<u>fall</u>**ing **<u>down</u>**

Figure 2. Example text for imagery condition with beat structure marked in bold and underlined.

Results

Group Analyses

Participants assigned to the exercise versus the anagram groups did not differ significantly in age, $t(37)= -1.70$, $p= .10$, or Gold-MSI musical training scores, $t(37)= 0.042$, $p= .97$. No significant differences were found between the two groups in terms of auditory imagery abilities, as measured by the BAIS vividness, $t(37)= -0.007$, $p= .99$, and BAIS control scales, $t(37)= -1.40$, $p= .17$.

Arousal Manipulation Check

The mean post-manipulation heart rate for the exercise group was 132.72 bpm in Block 2 and 130.18 bpm in Block 4; for the anagram group these values were 76.98 and 78.98 bpm respectively. A significant manipulation by heart rate interaction was found between pre- and post-manipulation heart rates in both the perception and imagery tasks (perception: $F(1,37) = 251.03$, $p < .001$, partial $\eta^2 = .84$, imagery: $F(1,37) = 311.88$, $p < .001$, partial $\eta^2 = .89$). This indicates that the exercise group showed a significant increase in heart rate following jogging in comparison to the post-anagram task heart rate levels of the anagram group.

Tempo Analyses

A ratio was calculated to express any change in chosen tempi after versus before the manipulation (exercise or anagrams). This was done for each song for each participant and for both the perception and imagery tasks. The ratios calculated for each song were then averaged over the 14 songs to provide an average measure of post-manipulation tempo change for each participant in each task (perception and imagery). The mean ratios for the perception and imagery tasks for each group are presented in Figure 3. A higher ratio indicates a larger post-manipulation increase in chosen tempi, with a ratio of 1 indicating no change between pre- and post-manipulation tempo. The mean ratios for the exercise group were greater than 1 in both the perception and imagery tasks (perception: 1.03, 95% CI [1.00, 1.06]; imagery: 1.06, 95% CI [1.04, 1.09]), indicating an overall increase in chosen tempi following the exercise manipulation. The 95% confidence intervals for the mean ratios of the anagram group straddled 1 in both conditions (perception: 1.00, 95% CI [0.99, 1.02], imagery: 1.03, 95% CI [0.99, 1.07]), indicating that chosen tempi ratios did not change significantly after that manipulation.

A 2x2 mixed ANOVA revealed a significant effect of manipulation type (exercise vs. anagrams) on chosen tempi ($F(1, 37) = 4.21$, $p = .047$, partial $\eta^2 = .10$). This means that the exercise group indicated that the melodies sounded “correct” at a faster tempo following the manipulation compared with the anagram group, regardless of whether a song was being perceived or imagined. No significant interaction between manipulation type and task type (perception vs. imagery) was found ($F(1, 37) = 0.073$, $p= .79$), indicating that the performance of the two groups in comparison to one another did not significantly differ between the perception and imagery tasks.

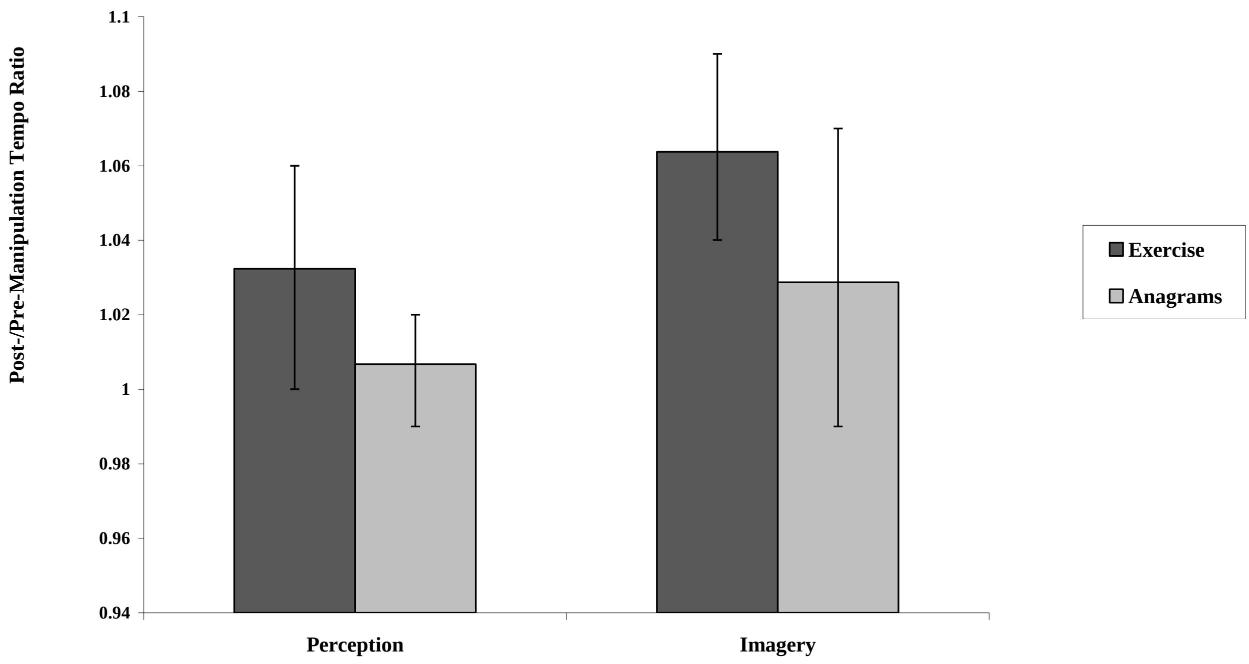

Figure 3. Mean ratios between post- and pre-manipulation chosen tempi for perception and imagery tasks (error bars represent 95% confidence intervals).

Individual Differences

Correlations between the chosen tempi ratios and the other experimental measures taken (age, Gold-MSI scores, BAIS, ratio of post-exercise HR to baseline HR) were calculated for each group separately. Significant correlations were found between some of the measures of music-related ability (exercise group: BAIS control and BAIS vividness, $r(18)=$

.80, $p < .001$; anagram group: BAIS control and BAIS vividness, $r(17)= .58$, $p = .009$, Gold-MSI and BAIS vividness, $r(17)= .57$, $p = .011$, Gold-MSI and BAIS control, $r(17)= .54$, $p = .016$), but not with any of the tempo change variables. A multiple regression analysis using age, Gold-MSI scores, BAIS scores, and heart rate change as independent variables also revealed no significant effects of these factors, or their interaction, on chosen tempi (all *p*s > .05).

Discussion

The results of the present study support the hypothesis that exercise-induced physiological arousal can increase the tempo at which a familiar song sounds “correct” regardless of whether the song is perceived or imagined. These findings provide evidence that the generally stable mental tempo representations for music found by previous researchers (Halpern, 1988; Levitin & Cook, 1996) can be altered in a systematic way. Our results extend previous findings, such those of Boltz (1994) who found an effect of arousal on spontaneous tapping speed, by demonstrating that arousal can influence chosen tempi for even highly familiar musical melodies that have long-term representations in memory. This is true even when the actual song is playing, which provides strong perceptual cues.

In relation to an internal clock model (Church, 1984; Gibbon, 1991), these results suggest an influence of pacemaker speed on temporal judgments for complex stimuli such as music. The tempo choice task employed in our study requires participants to make temporal judgments in real time as the stimulus is occurring. During a period of increased arousal, the pacemaker emits pulses at a faster than normal rate. This in turn would cause participants to set the music at a faster rate than in a non-aroused state to match the increased speed of pulse emission.

These findings also have implications for music performance. Performing music is a mentally and physically demanding task that can be accompanied by a great deal of anxiety, which may lead to substantial increases in heart rate and subjective arousal prior to and during a performance (LeBlanc, Jin, Obert, & Siivola, 1997). Our results suggest that even a moderate amount of physiological arousal (4 min of aerobic exercise) can increase chosen tempi for highly familiar music, providing impetus for future studies into the relationship between performance anxiety and tempo choices in performance. In the present study, no significant relationship was found between musical training and post-manipulation chosen tempi in the exercise group, suggesting that participants who were more highly trained in music were affected similarly to those with little or no training. However, as participants in the present sample were not specifically selected on the basis of musical training, a study involving a group comparison between professional musicians and non-musicians might provide further insight.

The present study found no influence of self-reported auditory imagery (BAIS scores) on post-manipulation chosen tempi in the exercise group. That is, participants who self-reported as being better able to imagine sounds vividly or control their auditory imagery were not more immune to the impact of arousal on chosen tempi. The ratio of participants' post-exercise heart rate to baseline heart rate also had no significant influence on chosen tempi following the exercise periods. A between-groups design to compare participants preselected on the basis of high versus low auditory imagery ability or a study in which multiple groups exercised at different levels of exertion might further elucidate any potential effects of these two variables in the future.

One limitation of the present study is the possibility that some participants may have inferred the experimental hypothesis, although none spontaneously reported this. However, it seems unlikely that demand characteristics, if present, could explain these results due to the fact that songs were always presented in a different order in different blocks, the Powermate dial has no markings that could be remembered across blocks, and the time delay between blocks makes it very difficult to retain prior tempo settings in memory.

In conclusion, the present study demonstrates that physiological arousal can influence temporal judgments for even complex and highly familiar stimuli such as well-known music. These results provide a rationale for examining the influence of other psychological factors known to influence time perception (e.g., age) and group differences (e.g., musicians vs. non-musicians) to provide a wider range of evidence as to how the speed of the internal clock influences temporal judgments within the music domain.

References

Boltz, M.G. (1994). Changes in internal tempo and effects on the learning and remembering of event durations. *Journal of Experimental Psychology-Learning Memory and Cognition*, *20*, 1154-1171.

Church, R.M. (1984). Properties of the internal clock. *Annals of the New York Academy of Sciences*, *423*, 566-82.

Gibbon, J. (1991). Origins of scalar timing. *Learning and Motivation, 22,* 3-38.

Grommet, E. K., Droit-Volet, S., Gil, S., Hemmes, N. S., Baker, A. H., & Brown, B. L. (2011). Time estimation of fear cues in human observers. *Behavioural Processes*, *86*, 88-93.

Halpern, A. R. (1988). Perceived and imaged tempos of familiar songs. *Music Perception, 6,* 193–202.

Hubbard, T.L. (2010). Auditory imagery: Empirical Findings. *Psychological Bulletin, 136,* 302-329.

Iwanaga, M. (1995). Relationship between heart rate and preference for tempo of music. *Perceptual and Motor Skills, 81*(2), 435-440.

LeBlanc, A., Jin, Y.C., Obert, M., & Siivola, C. (1997). Effect of audience on music performance anxiety. *Journal of Research in Music Education, 45*, 480-496.

Levitin, D. J., & Cook, P. R. (1996). Memory for musical tempo: Additional evidence that auditory memory is absolute. *Perception & Psychophysics, 58,* 927-935.

Miró, E., Cano, M. C., Espinosa-Fernández, L., & Buela-Casal, G. (2003). Time estimation during prolonged sleep deprivation and its relation to activation measures. *Human Factors, 45,* 148-159.

Müllensiefen, D., Gingras, B., Stewart, L., & Musil, J. (2011). *The Goldsmiths Musical Sophistication Index (Gold-MSI): Technical Report and Documentation v0.9*. London: Goldsmiths, University of London.

Murray, N.P., & Russoniello, C. (2012) Acute physical activity on cognitive function: A heart rate variability examination. *Applied Psychophysiology & Biofeedback*, *37*, 219–227.

North, A.C., & Hargreaves, D.J. (2000). Musical preferences during and after relaxation and exercise. *The American Journal of Psychology*, *113*(1), 43-67.

Ozel, S., Larue, J., & Dosseville, F. (2004). Effect of arousal on internal clock speed in real action and mental imagery. *Canadian Journal of Experimental Psychology-Revue Canadienne De Psychologie Experimentale*, *58*, 196-205.

Pastor, M. A., Artieda, J., Jahanshahi, M., & Obeso, J. A. (1992). Time-estimation and reproduction is abnormal in Parkinsons-disease. *Brain*, *115*, 211-225.

Pontifex, M.B., & Hillman, C.H. (2007). Neuroelectric and behavioral indices of interference control during acute cycling. *Clinical Neurophysiology, 118,* 570–580.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review*, *103*, 403-428.

Schwarz, M.A., Winkler, I., & Sedlmeier, P. (2013). The heart beat does not make us tick: The impacts of heart rate and arousal on time perception. *Attention, Perception, & Psychophysics*, *75*, 182-93.

Wearden, J.H., Pilkington, R., & Carter, E. (1999). ‘Subjective lengthening’ during repeated testing of a simple temporal discrimination. *Behavioural Processes, 46*, 25–38.

Wittmann, M., Leland, D. S., Churan, J., & Paulus, M. P. (2007). Impaired time perception and motor timing in stimulant-dependent subjects. *Drug and Alcohol Dependence, 90,* 183-192.

Zakay, D., & Block, R.A. (1996). The role of attention in time estimation processes. *Advances in Psychology, 115,* 143-164.

Zatorre, R. J., & Halpern, A. R. (2005). Mental concerts: Musical imagery and the auditory cortex. *Neuron, 47,* 9–12.