EFFECTS OF ENGAGEMENT LEVEL ON A TIMING TASK

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ABSTRACT

The ability to time one's action is important as they progress through their day-to-day life because everything requires time, and one must be able to predict to some extent when events may occur so their actions are timed appropriately and accurately. By tuning the internal timekeeper mechanism, one may be able to strengthen their ability to predict and time their actions. Many factors could influence how the internal timekeeper is tuned, and I examined one of these factors in the current study: level of engagement with a finger-tapping timing task. Experimental groups were based on whether participants were more actively or passively engaged with the tapping task, depending on whether the participants were instructed to tap in time with a metronome during the initial familiarization period (active engagement) or just listen to the metronome during this period (passive engagement). Two different timing intervals (500ms & 2000ms) were also used to determine if there would be differences between groups at different time lengths between the metronome beats. I predicted that those more actively engaged with the task would perform better than those more passively engaged, particularly at the longer timing interval, because of the coordination of perceptual and motor information these participants experienced during the familiarization period, rather than just attending to the perceptual information. However, the results indicated that there were no significant differences in performance between groups at either timing interval. These findings suggest that it may not matter whether one is more actively or passively engaged

with a simple task like the one used in this study in order for accurate and effective timing to take place.

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CHAPTER I

INTRODUCTION

The ability to time actions is an important aspect of everyday life; everything from holding conversations and playing sports to sleeping and eating requires time. While most common uses of time occur on larger scales, such as those just listed, measuring the time it takes to complete given tasks often begins on smaller scales where the contractions of various muscles influence the ability to control one's movements accurately. People must then be able to judge time appropriately so they can act accordingly with their environment and move through their day and whatever activities they encounter. Without the skill to judge time, functioning properly in daily life would become challenging. Most daily actions consist of one being directly involved with the task at hand and influencing when and how certain actions take place. However, what happens if someone is not directly and actively involved with the task and is instead more indirectly and passively involved with the task? Are they still able to have an influence on when and how certain actions take place?

The answer to those questions was the focus of the present study; it attempted to shed light on the relationship between an actor's level of engagement with a timing task and their ability to time their actions. Active and passive engagement were examined in a time interval reproduction task where participants were initially familiarized with target tempi through a metronome and were instructed to reproduce those target intervals on their own, without the guidance of the metronome. Participants in an active engagement group were instructed to tap along with the metronome during the familiarization period, and participants in a passive engagement group were instructed to just listen to the metronome during the familiarization period. Differences in timing performance between engagement groups when the metronome was absent was of interest in the current study. Before providing additional information about the current study and specific hypotheses, I will provide a review of relevant information regarding timing research in general and the idea of active and passive engagement as it relates to the concept of perceptual learning.

Background in Timing

The ability to time actions comes from the idea of planning and coordinating one's motor responses to achieve a temporally constrained goal, and this ability can be influenced by the goal one is trying to complete. It is believed that the planning and coordination of movements and actions involves some kind of internal timekeeper, an internal signal people use to judge time in the absence of an external stimulus to regulate time, as evidenced by the model developed by Wing and Kristofferson (1973). This model, used as a basis for timing research since its inception, described the variability between one's actual and expected motor responses to external stimuli or internal forces as a function of both the processes of the internal timekeeper itself and response delay processes. The timekeeper processes are the intervals between clock pulses that act as triggers for a certain motor response, and the response delay processes are the time differences between the internal signal for the motor response and the actual production of the motor response. Most of the variability in motor timing responses comes from the response delay processes due to all the different external and internal variables that could influence delays in responses.

Controlling for all the variables that may influence one's timing would be difficult, but the best way that has been found to study timing is in a controlled experiment where participants are asked to complete a finger-tapping task and tap in time with a repeated external stimulus, usually the sound of a metronome (Wing, 2002). Using such a simple task allows researchers to look more deeply into the role of the internal timekeeper (Flach, 2005) and understand how participants manage to stay in time with the external stimulus even when the external stimulus is removed, as was the case for the current study. This task is known as the *synchronization-continuation paradigm* (e.g., see Wing, 2002). As shown in Figure 1a, this paradigm is comprised of two phases: (1) during the *synchronization phase*, participants tap along with the steady metronome to become accustomed to the tempo of the beat and tune the internal clock, and (2) during the *continuation phase*, participants continue tapping without the sound of the metronome to the same tempo that was previously presented as a way to determine how "in tune" the internal clock is with the tempo set.

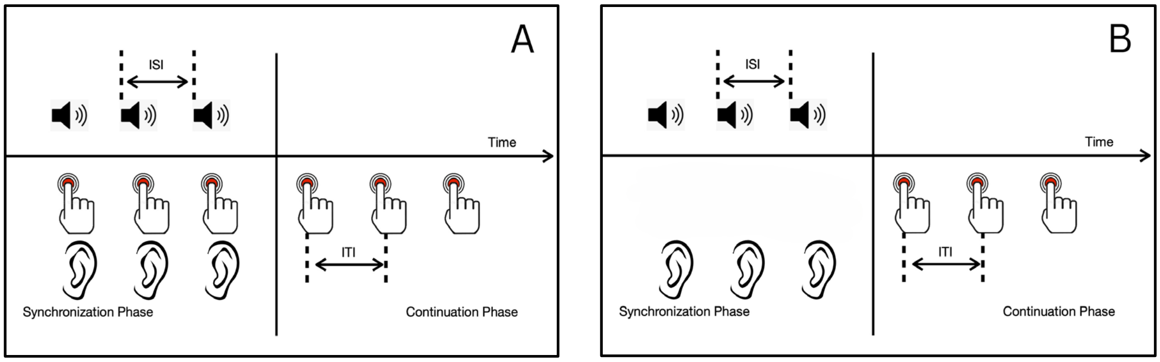

Figure 1. (A) The experimental design for the active engagement group where participants listened to and tapped along with the sound of the metronome during the synchronization phase before the metronome was removed for the continuation phase. (B) The experimental design for the passive engagement group where participants just listened to the sound of the metronome during the synchronization phase before the metronome was removed for the continuation phase and began tapping at the target interval. (Adapted from [Petilli et al., 2018].)

There are different theories regarding how the internal timekeeper operates and what may influence one's timing abilities (Repp & Steinman, 2010; Bååth et al., 2016; Studenka et al., 2018), but an important factor that may influence timing ability in the current study, and the use of the synchronization-continuation paradigm, was the external and internal cues or signals one experiences. External signals are easier to notice because they usually involve an outside influence to effectively time one's own actions, such as paying attention to cues during a conversation to know whether the speaker and listener roles are being switched or maintained (Latif et al., 2018). The external signal in the case of the current study was the sound of the metronome as a source of feedback when calibrating one's internal clock during the synchronization phase. By using the reference of the metronome, participants may be able to tell whether their taps are in time with the metronome or slightly ahead or behind the metronome. Participants could then engage in feedback processes to make sure their taps are as accurate as possible in relation to the metronome, such as tapping a little sooner if they notice their taps occurring after the metronome beats.

Conversely, internal signals are more difficult for others to notice because they are mainly only accessible by the person generating the signal and tend to become apparent to others when an observable behavior is related to the signal, such as resting the body based on the circadian rhythm (Bao et al., 2015). In the current study, the internal signals were the result of feedforward processes during the continuation phase when the metronome was no longer present. Rather than using the reference of the metronome to adapt their timing, participants would instead have to rely on their internal representation of the metronome and anticipate when the metronome would beat, as if the metronome was still being played. It becomes more challenging to tell how accurate one's tapping rate is compared to the target tempo without the reference of the metronome, which then makes adjusting the tapping rate relative to the target tempo more difficult.

With these ideas of timing in mind, my goal in the current study was to examine how two different forms of task engagement might influence one's ability to time their actions accurately. The traditional synchronization-continuation paradigm was used as a basis for the design, but it was adapted to include a passive engagement group to compare timing performance to an active engagement group. Participants in the active engagement group were instructed to complete the synchronization phase as usual (see Figure 1a); however, participants in the passive engagement group were instructed to only listen to the metronome during the synchronization phase and instructed to begin tapping only after the metronome was turned off during the continuation phase (Figure 1b). To my knowledge, previous studies have not used a condition of this paradigm where participants were only exposed to the metronome without tapping during the synchronization phase. I designed the current study to allow for a comparison of these methods in determining what may be necessary for effective timing.

Level of Engagement

In the current study, active and passive engagement were conceptualized as whether a motor response was paired with the processing of perceptual information in order to achieve a given goal. This conceptualization and the experimental design for the current study were influenced by Held and Hein (1963), who used similar definitions when trying to determine if individuals could develop stronger perceptual skills by moving through their environment themselves or if having someone or something else move them instead would suffice. To test this, these researchers used pairs of kittens reared in darkness from birth, except during the experiment itself, that were exposed to similar yet different conditions. The two conditions exposed the kittens to the same visual stimuli and apparatus, but only one condition (active) allowed the kittens to more freely engage in motor actions and move around the environment within the confines of the apparatus around their neck. The other condition (passive) restricted the other kittens so that these kittens only moved through the environment based on the movements of the more unrestricted kitten (Figure 2). After six weeks of being exposed to this setup, the pairs of kittens completed a series of visual-motor tests to assess their perceptual skills. The kittens that were less restricted during the initial setup performed better on the perceptual tests and had perceptual abilities that more closely resembled “normal” kittens compared to their more restricted counterparts. These findings support the idea that visual perception paired and coordinated with motor response allows for the development of stronger connections between perception and action, which was used as a foundation for the current study and hypotheses.

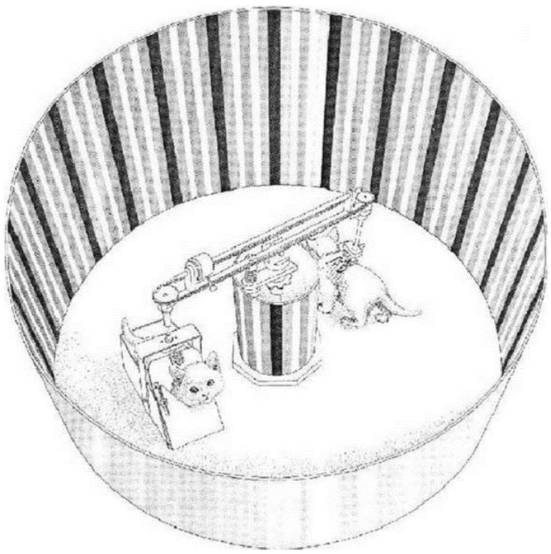

Figure 2. An example of the experimental design used by Held and Hein (1963). (Suzuki, Floreano, & Di Paolo, 2005)

Perceptual Learning

Studies like Held and Hein (1963) provided an early view of perceptual learning, which posits that information from the sensory systems may influence one's understanding of their environment and how to respond to various stimuli. Part of the learning process comes from practice and repetition, as actively practicing a task could allow one to refine their perceptual abilities (Seitz & Dinse, 2007), and performance on certain tasks can be maintained over time through repetitions of those experiences (Shibata et al., 2014). However, it may be possible for learning to occur passively as well because people are constantly using multiple sensory systems to take in information about their environment, regardless of whether it is done consciously. The combination of multisensory systems to perceive and interpret one's surroundings, including learning, could help make the associations between the various systems stronger (Shams et al., 2011).

Rather than using a multisensory approach, I used a multimodal approach in the current study to study the idea of perceptual learning as it relates to timing performance. The coordination of auditory perception and motor response (or lack thereof) could help determine whether the associations between stimulus and response were improved or hindered. Only perceiving an auditory stimulus without the coordinated motor response – such as in the case of the passive engagement group used for this study – may lead to weaker associations and coordination between perception and action, and subsequently lead to weaker learning of the task overall. When performing in a group, musicians, for example, must pay attention to the visual and auditory cues around them in order to engage in an action to play at just the right time (Love et al., 2012); otherwise, the piece may not sound as it was intended.

The conceptualizations of active and passive engagement used for the current study can be thought of in terms of perceptual learning through a multimodal approach because the idea of learning is thought to occur through direct involvement with a task most of the time. Being more actively engaged with a given task and one's environment may require more effortful and deliberate attention to the relevant stimuli, which, in turn, may improve one's skills and abilities. By including a condition of passive engagement in the current study, a comparison between groups could be made to determine whether there are differences in learning based on level of engagement with the task. It could be argued that the improvement of learning and performance of a task could be due to not the utilization of more than one sensory system, but rather increased modalities and the involvement of an action in coordination with the perceptual information to engrain the relevant information of the task to memory. The results of the Held and Hein (1963) study suggest that performance should be enhanced in the active engagement group due to the coordination of perception and action through extra practice and repetition that are absent in the passive group, in which learning was only through perception.

Current Study

In the current study, I used a variation of the traditional tapping task paradigm to examine how one's level of engagement with a task (active vs. passive) influenced participants' ability to time their actions, where engagement was defined as how involved participants were with the task during the synchronization phase (see Figure 1). As far as I know, previous studies have not used a design where participants were only exposed to the metronome without tapping during the synchronization phase. This design allowed for a comparison of these methods in determining what may be necessary for effective timing. In addition to the two experimental groups, I also used two different inter-stimulus intervals (ISIs; 500ms & 2000ms) in the current study to determine whether differences between engagement groups at different timing intervals would be observed. Previous research (Miyake et al., 2004; Bååth et al., 2016) has suggested that when the time between metronome beats is shorter (meaning the tempo is faster), tapping in time with the metronome occurs more automatically than when the time between beats is longer (and the tempo is slower). The slower tempos require more conscious attention to the timing interval to ensure one is tapping in time with the sound of the metronome during the synchronization phase and maintaining the tempo during the continuation phase.

When using an experimental design like the one used in the current study, researchers often assess timing performance using measures of participants' inter-tap interval (ITI), which is the time between consecutive taps participants make during both the synchronization and continuation phases; however, in the current study, the focus was on analyses of the ITIs produced only during the continuation phase. The ISI is the time between each beat of the metronome during the synchronization phase and sets the target tempo participants should follow when tapping without the metronome during the continuation phase.

The main dependent variables used for the current study were the participants' mean ITI, which provides information about how close their internal representation of the tempo was to the target ISI on the average, and the standard deviation of participants' ITI, which reflects their variability in timing performance relative to their mean ITI and their internal representation of the target ISI. Measuring timing performance during the continuation phase allowed for an assessment of the strength of the internal representation of the target timing interval when participants performed without the presence of the metronome for both the active and passive engagement groups.

Hypotheses

Broadly speaking, based on the findings of Held and Hein (1963), I expected that participants in the active engagement group would have better timing performance than participants in the passive engagement group because they would be able to encode the temporal information of the metronome both perceptually through the sound of the metronome and motorically by tapping with it during the synchronization phase. Performance was also expected to be better at shorter ISIs because timing is more automatic and requires less conscious attention at faster tempos (Miyake et al., 2004; Bååth et al., 2016), which would allow there to be an interaction between engagement group and ISI. The left panel of Figure 3 highlights the hypothesized interaction between engagement groups based on the mean ITI. Only small differences were expected between the active and passive engagement groups at the shorter ISI (500ms). When the ISI gets longer (2000ms), however, there was an expectation that the internal representations of the target interval would be different between the engagement groups, with the active engagement group having an internal representation associated with larger mean ITI values than that of the passive engagement group. The right panel of Figure 3 shows the hypothesized interaction between groups based on the standard deviation of the ITI. Again, only relatively small differences in variability were expected between the active and passive engagement groups at the shorter ISI, with the active group having less variability in their timing performance. However, greater differences were expected as the ISI gets longer, with higher variability for both the active and passive engagement groups but even more so for the passive engagement group.

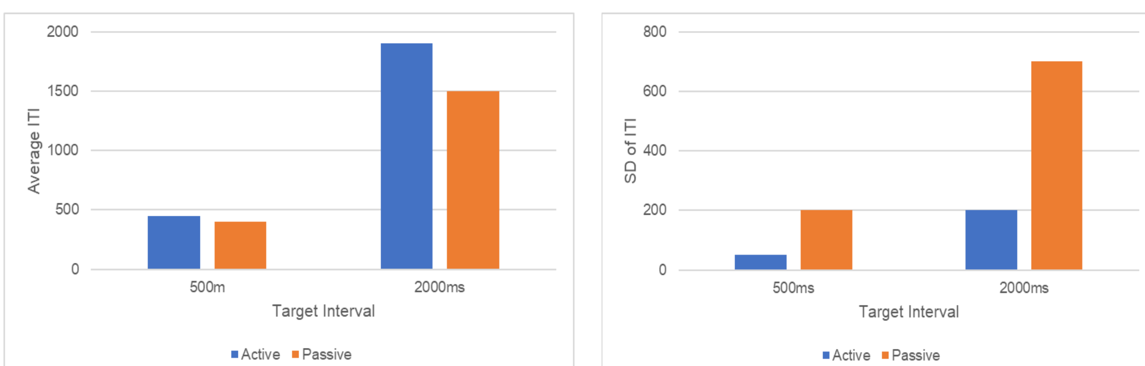

Figure 3. Expected differences in mean ITI (left) and SD of ITI (right) between active and passive engagement groups at both 500ms and 2000ms ISI levels.

As well as examining the overall relationship between engagement level and timing performance, it was also of interest to provide a more fine-grained assessment of the hypothesized relationship by examining between-engagement-group changes in performance as time during the continuation phase progressed. Examining timing performance in this way could help characterize the stability of the internal representation as a function of engagement level and the target interval. Taking the predictions from the previous hypotheses into account, I further hypothesized that a weaker internal representation might be reflected by both drifts in the mean ITI from the target and growth in variability as time into the continuation phase progressed. That evolution might be most pronounced in the passive engagement group at the longer ISI level (2000ms). The details of this analysis are described more thoroughly in the following section, but the standard deviation of participants' ITI was the main dependent variable for the analysis.

As shown in the left panel of Figure 4, participants in both the active and passive engagement groups were expected to have relatively low variability in their timing performance for the short ISI (500ms) condition, with the active engagement group having the lower variability. As participants completed the continuation phase of the task, I expected that variability in both groups would increase, but the variability for the passive engagement group would increase more rapidly. The same pattern of results was expected for both engagement groups for the longer ISI (2000ms); however, the differences between the active and passive engagement groups were expected to be more pronounced toward the end of the continuation phase, with the passive engagement group expected to have the highest variability (Figure 4, right).

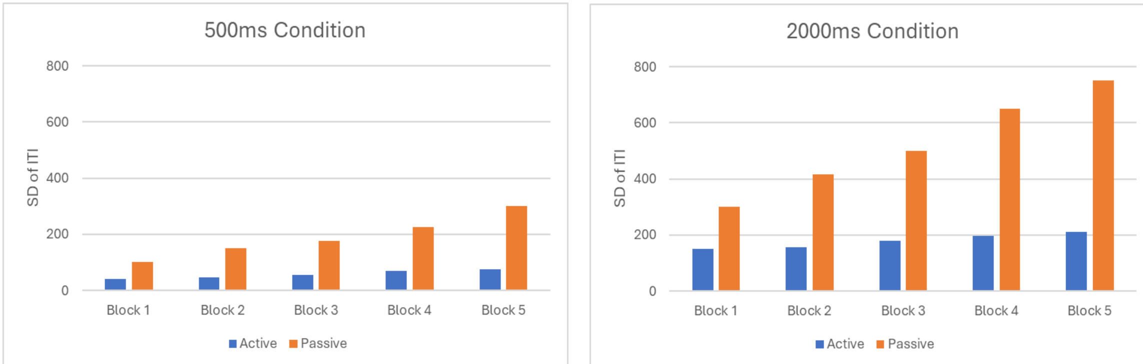

Figure 4. Expected differences in the standard deviation of ITI based on ISI level, block of continuation ITIs, and engagement level (500ms, left; and 2000ms, right).

CHAPTER II

METHODS

Participants

Participants were recruited from the Cleveland State University Psychology Research Participant Pool. All participants gave their informed consent electronically before beginning the study, and they received research participation credit after completing the study. The final dataset included data from 155 participants[1] after seven participants were removed prior to conducting the final analyses for the following reasons: three for repeating important parts of the experiment more than once[2], two due

[1] A post-hoc power analysis conducted with G*Power using input parameters from the collected data including $\alpha = .05$, $f = .084$, and $n = 155$ yielded an achieved power of 0.547, based on the engagement group by ISI interaction. Therefore, the results of the current study were underpowered in part due to the small effect size found. An additional 127 participants would be needed to achieve a power of at least 0.80 using the effect size found for the current study ($f = 0.084$). Conversely, through a sensitivity analysis, an effect size of 0.113 would be needed given the sample size for this study (155) to achieve a power of at least 0.80. The original target number of participants ($n = 150$) was achieved before the end of a semester; however, data collection continued as there was still time left in the semester, and an additional 62 participants completed the study. The analyses reported in this thesis only included participants up to the target number was reached. Including those additional participants in the analysis would have only increased the power to 0.692, assuming all data are valid and not outliers or excluded based on methods described. While this study was underpowered, the number of participants in this study was much higher than previous in-person studies related to timing (i.e. see Repp & Steinman, 2010; Studenka et al., 2018; Bååth et al., 2016).

[2] Due to the online nature of this study, participants could begin the study whenever they wanted. Participants may have misjudged the time it would take to complete the study and completed some of the experimental conditions before exiting the study and starting it again when they had more time available to complete it.

to technical issues with the program, one for failing to follow instructions[3], and one due to reporting a TBI. Further analyses into more potential outliers revealed no statistically significant differences between the dataset used and those that used the IQR or Median Absolute Deviation (MAD) methods as exclusionary criteria (see Appendix A). There were 82 participants in the active engagement group (M_{age} = 19.76, 59 females) and 73 participants in the passive engagement group (M_{age} = 19.86, 47, females). All participants had normal or corrected to normal vision and reported no hearing or psychological impairments. Additionally, most participants were right-hand dominant (134) rather than left-hand dominant (16) or ambidextrous (5).

Apparatus and Design

Participants completed the present study entirely online and remotely via each participant's laptop or desktop computer using the LabVanced platform (Finger et al., 2017). It has been found that Google Chrome offers the clearest and most consistent delivery of the audio stimuli, so participants were required to use that browser. The experimental conditions, including the delivery of the audio stimuli, were programmed and conducted through the LabVanced platform, and participants were instructed to use headphones to listen to the stimuli. To help ensure participants were focused on the study, the visual display associated with the experiment filled the full computer screen. Participants only used specific keys on a standard QWERTY keyboard to respond to instructional prompts (enter key) and complete the experiment (spacebar). Although

[3] This participant produced 226 ITIs during the synchronization phase for the 2000ms conditions (mean ITI = 187.388) and 61 ITIs during the synchronization phase for the 500ms condition (mean ITI = 166.853). Therefore, it could be concluded that the participant was clearly not complying with the task instructions.

participants were asked about their hand dominance, they could respond with whichever hand they felt most comfortable.

In the current study, all experimental conditions used the modified synchronization-continuation paradigm with two phases: a synchronization phase always preceded a continuation phase. During the synchronization phase, participants attempted to align their internal clock with the steady sound of a metronome; however, during the continuation phase, participants attempted to reproduce the steady tempo they heard but in the absence of the metronome. An active engagement group and a passive engagement group were used as experimental groups for this study, and the main difference between these groups came during the synchronization phase of the timing task. Participants in the active engagement group were instructed to press the spacebar in time with the metronome during the synchronization phase, and participants in the passive engagement group were instructed to just listen to the metronome during the synchronization phase while keeping their body still. During the continuation phase, both groups of participants were instructed to reproduce the target interval imposed by the metronome (see Figure 1).

Across the synchronization and continuation phases of a unique experimental condition, a single target time interval was in force. The ISI was the tempo participants heard through the metronome during the synchronization phase and the target interval they attempted to reproduce during the continuation phase. For this study, a short interval (500ms) and a long interval (2000ms) were used as the ISI levels. Differences in performance quality between groups during the continuation phase were of main interest, and any such differences could be attributed to differences in the conditions imposed during the synchronization phase. This conclusion could be particularly true if there were differences found at the different timing intervals as well.

Procedure

After providing consent electronically, participants completed a headphone check to verify they were wearing headphones and the headphones were working properly (Woods et al., 2017). For this check, participants were instructed to select the quietest tone in a series of three tones; however, an anti-phase tone was disguised as the quietest if one's headphones were not worn, and the tone was instead played through the computer's speakers. Participants were given the opportunity to repeat the headphone check up to three times if they did not pass it at first. For this study, passing the headphone check meant participants correctly identified the quietest tone at least 11 times out of 12 trials in an attempt. Of the 155 participants, only five did not pass this headphone check in three attempts, but it did not influence the results of the experiment.[4] Following the headphone check, participants completed a demographic questionnaire before being randomly assigned to either the active or passive engagement experimental group. Based on their assigned experimental group, participants completed a practice condition of the study to help them become familiar with the experimental task without being exposed to the full experimental conditions. Prior to the practice condition, all participants were prompted to adjust their seating and audio levels for their comfort if needed. To maintain attention on the experiment, participants were also instructed to

[4] Excluding participants based on whether they passed or failed the headphone check did not change the significance of the results on any of the dependent variables. All analyses reported included all 155 participants.

focus on a fixation cross in the center of the screen for the duration of the practice condition and each experimental condition.

Once they began practice, a series of metronome beats was played with an ISI of 1250ms, an interval at the midpoint of the experimental ISI levels (500ms & 2000ms). During the practice condition, 10 ISIs were produced through 11 metronome beats during the synchronization phase where participants in the active engagement group were instructed to press the spacebar along with the metronome and participants in the passive engagement group were instructed to just listen to the metronome while keeping their body still[5]. During the continuation phase, both groups of participants were instructed to press the spacebar at the target tempo without the presence of the metronome, producing 25 ITIs through 26 spacebar presses.

Following the completion of the practice condition and before continuing to the experimental conditions, participants could take a short break to readjust their audio levels and environment, if needed. For both experimental groups, participants completed the experimental conditions in a similar fashion to the practice condition, but at two ISI levels (500ms & 2000ms). The order of the two ISI-level conditions was presented to each participant in a randomized order. At each ISI-level condition, 20 ISIs were produced by 21 metronome beats during the synchronization phase where, again, participants in the active engagement group were instructed to press the spacebar along with the metronome and participants in the passive engagement group were instructed to

[5] During the practice condition, there were eight participants in the passive engagement group who pressed the spacebar during the synchronization phase no more than three times. However, none of these participants pressed the spacebar during the experimental conditions at either ISI level.

just listen to the metronome while keeping their body still[6]. All participants were then instructed to press the spacebar at the target tempo, again in the absence of the metronome, producing 100 ITIs during each continuation phase through 101 spacebar presses. (See Appendix B for the specific instructions participants in both engagement groups received.)

After completing both experimental conditions, participants completed a portion of the Goldsmiths Musical Sophistication Index (Gold-MSI; Müllensiefen et al., 2014) to assess their general musical sophistication and musical experience. This scale was used to determine any possible relationship between participants' timing performance and their musical sophistication and experience, although such analyses were outside the scope of this thesis. Once finished with this self-report measure, participants were debriefed, given an opportunity to submit any questions they had about the study, and thanked for their time before closing their browser and receiving the research participation credit.

Data Analysis

The inter-tap interval (ITI) – the time between consecutive taps during the continuation phase – was the main measure of timing performance and was used to calculate the dependent variables used in the current analysis. Within the active and passive engagement groups, the mean and standard deviation of the ITI were found for each participant at each experimental ISI level during the continuation phase of each timing task. The difference in continuation timing performance between engagement groups was of particular interest in this study. However, it was also of interest to

[6]During the experimental conditions, there were a total of four participants in the passive engagement group who pressed the spacebar no more than two times during the synchronization phase. There were two participants who pressed during the 500ms condition and two during the 2000ms condition. None of these participants also pressed the spacebar during the practice condition.

determine how between-group differences might be modulated by the target ISI duration. To assess any changes in timing between the groups, the mean and standard deviation of the ITI were analyzed through a two-way engagement group (active or passive) by ISI level (500ms & 2000ms) mixed-design ANOVA[7], where engagement group was a between-participants factor and ISI was a within-participants factor. The mean ITI provided an estimate of how close the internal representation of the target time interval was to the target time interval itself (the ISI). The standard deviation of the ITI reflected the within-condition variability of participants' timing performance and, therefore, the stability of the internal representation of the target interval.

In addition to the two-way ANOVA, a three-way mixed-design ANOVA was used to assess changes in the mean and standard deviation of the ITI, which included engagement group and ISI level as noted above and included a blocking variable during the continuation phase of the experiment as an additional within-participants factor. For the block-interval variable, the 100 ITI values recorded during the continuation phase were subdivided into five blocks of 20 ITIs. The means and standard deviations of ITI for each block were calculated for each participant at each ISI level.[8] Comparing engagement groups using this analysis could help determine how active vs. passive engagement might

[7] Assessments of the normality of ITI distributions indicated that each ITI distribution within each group and at each ISI level for all dependent variables the data were strongly positively skewed, and thus violated the assumption of normality (all Shapiro-Wilk tests of normality > .104, ps < .001). However, researchers have argued that violating the normality assumption may be less of an issue if the other assumptions have been satisfied (Knief & Forstmeier, 2021). The data from the current study have met the assumptions of independence and homoscedasticity across groups. To my knowledge, previous timing research has not reported whether that data violated the normality assumption; therefore, it is unclear 1) whether the ITI distribution non-normality reported here is typical of other continuation-phase ITI distributions in the interval timing literature and 2) how to address ITI distribution non-normality.

[8] The assumption of sphericity was violated for the blocking variable; therefore, the reported results that include this variable as a main effect or interaction term are based on the Greenhouse-Geisser correction for sphericity.

differentially influence the stability of timing performance as the continuation phase progressed. In turn, group differences in timing performance as the continuation phase progressed may reflect differences in the strength the active vs. passive conditions had on encoding the target time interval.

CHAPTER III

RESULTS

In the present study, the group-mean ITI was analyzed with respect to changes in both ISI level and engagement group. Overall, I expected that timing performance in terms of the mean ITI would be better for the active engagement group particularly at the longer ISI level, noted by main effects for ISI and engagement group and an interaction between these variables (see Figure 3, left). As shown in Figure 5, for both the active and passive engagement groups, there were similar increases in the group-mean ITI with the increase in ISI level; for both groups, the group-mean ITI was a close match to each target ISI level (see Table 1). The increase in the group-mean ITI with ISI resulted in a significant main effect for ISI ($F_{1,\,153}$ = 2010.393, p < .001, partial η^2 = .929). A significant main effect for engagement group was not found for the mean ITI, though it approached significance ($F_{1,\,153}$ = 3.637, p = .058, partial η^2 = .023). In addition, the engagement group by ISI interaction was not significant ($F_{1,\,153}$ = 1.511, p = .221, partial η^2 = .010). The between-group similarities in the matching of the target tempo during the continuation phases suggest that, on the average, participants in each group had developed an internalized tempo during the synchronization phase that was matched to both the 500ms and 2000ms ISI levels.

Table 1.
Group-mean Differences for all Dependent Variables

	500ms		2000ms	
	Active	Passive	Active	Passive
Mean ITI	474.992	516.543	1932.169	2055.865
SD of ITI	50.075	216.256	332.517	623.135
CoV	0.121	0.160	0.199	0.238

Note. ITI = Inter-tap interval; CoV = Coefficient of variation

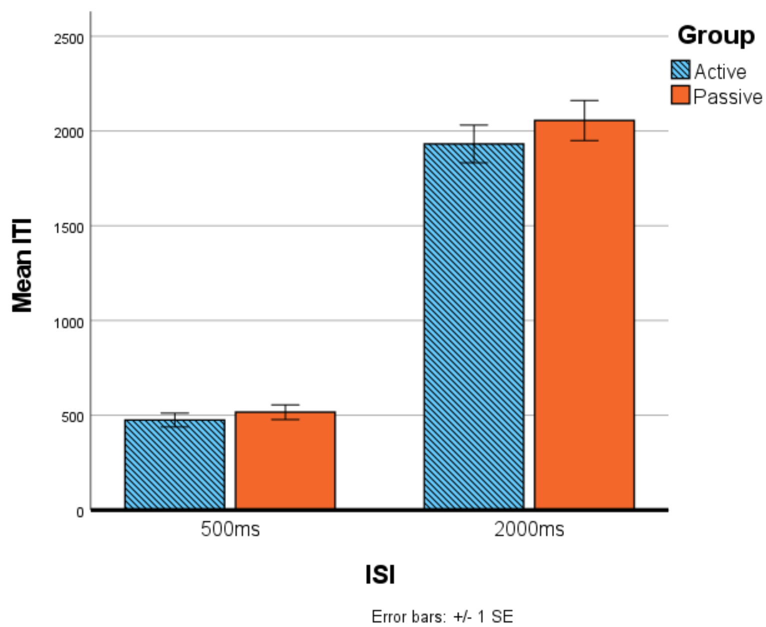

Figure 5. The group-mean ITI differences for the active and passive engagement groups at both 500ms and 2000ms ISI levels. Error bars reflect the standard error of the mean.

The standard deviation of the ITI reflects the amount of variability there is in participants' continuation timing performance as they tried to match their taps to the target time interval set by the metronome during the synchronization phase. Overall, I expected that variability in timing performance would be lower for the active engagement group particularly at the longer ISI level, noted by main effects for ISI and engagement group and an interaction between these two variables (see Figure 3, right). The increase for the standard deviation of the ITI from the 500ms to 2000ms ISI levels yielded a significant main effect for ISI ($F_{1, 153} = 32.666$, $p < .001$, partial $\eta^2 = .176$). A significant main effect for engagement group was not found for the standard deviation of ITI ($F_{1, 153} = 1.127$, $p = .290$, partial $\eta^2 = .007$), which led to a non-significant interaction between ISI level and engagement group as well ($F_{1, 153} = 1.065$, $p = .304$, partial $\eta^2 = .007$). These results indicate, as shown in Figure 6, that as expected, participants had lower variability in their timing performance at the shorter ISI level (500ms) where completing the task could be done more automatically and with less conscious attention needed than at the 2000ms condition (Miyake et al., 2004; Bååth et al., 2016). This finding is also consistent with previous research, which indicates that ITI variability increases as the ISI increases. However, the absence of a main effect for engagement group and an interaction with ISI level could be due to the large amount of between-participant variability within each group based on the size of the error bars shown.

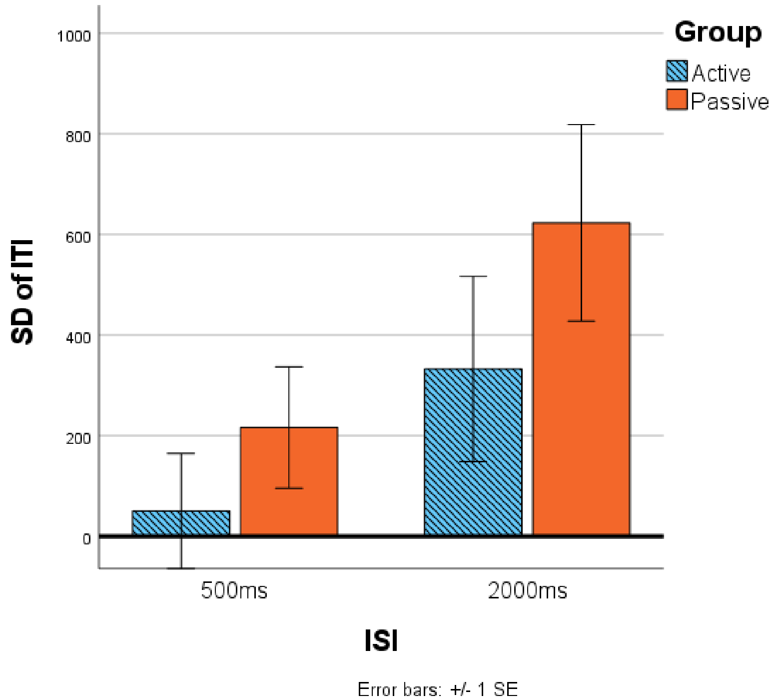

Figure 6. The group-mean differences in the standard deviation of ITI between active and passive engagement groups at both 500ms and 2000ms ISI levels. Error bars reflect the standard error of the mean.

As noted previously, the findings of increases in ITI variability as the ISI increases are consistent with previous research. To better compare the differences between engagement groups across the two ISI levels used in this study, the coefficient of variation (CoV) was used as a supplemental dependent variable so that participants' level of variability could be scaled or normalized relative to their mean ITI at each ISI level. The coefficient of variation, used in the same way as the mean ITI and standard deviation of the ITI in a two-way ANOVA, was calculated by dividing each participant's standard deviation of their ITI by their mean ITI for each ISI level. Within each of the four unique conditions, the individual-participant CoV values were averaged, and the group means were plotted in Figure 7. Following the results for the mean and standard deviation of the ITI, a significant main effect for ISI level was found using the coefficient of variation ($F_{1,}$

$_{153} = 14.800$, $p < .001$, partial $\eta^2 = .088$). However, a significant main effect for engagement group ($F_{1,\,153} = .238$, $p = .626$, partial $\eta^2 = .002$) and an interaction between ISI level and engagement group were not found ($F_{1,153} = 0.000$, $p = .994$, partial $\eta^2 = .000$). Thus, the pattern of statistical results for the coefficient of variation matched the results reported for the group-mean ITI and the group-mean standard deviation of the ITI.

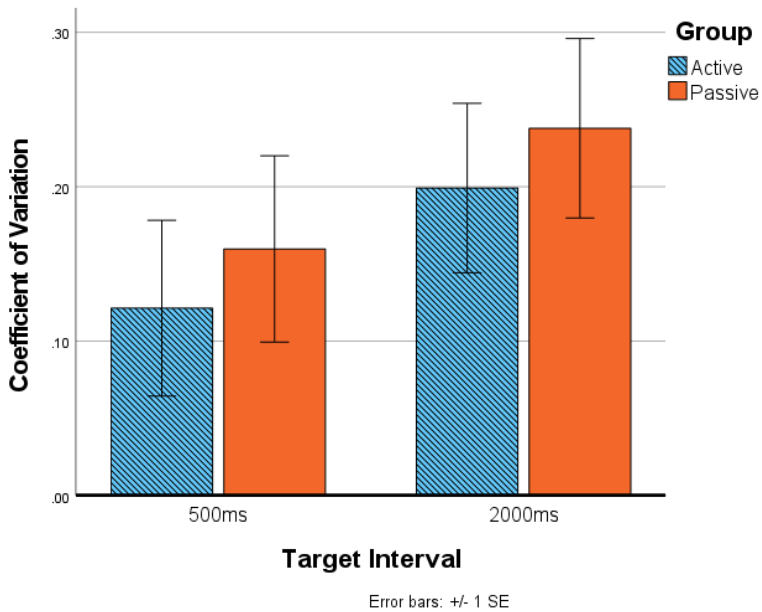

Figure 7. The group-mean differences in the coefficient of variation for ITI between active and passive engagement groups at both the 500ms and 2000ms ISI levels. Error bars reflect the standard error of the mean.

The main focus of this study was to examine differences between engagement groups to determine whether being more actively or passively engaged with the task influences one's timing performance, as well as identifying whether there are group differences at various time intervals. However, an additional step to examine this relationship deeper was to see how stable the timing mechanism was as participants progressed through the continuation phase of the task using a block variable in a three-way ANOVA with the coefficient of variation as the dependent variable. Using the standard deviation provides the best representation of variability and stability over time, but using the coefficient of variation, again, allows the standard deviation to be normalized to the mean ITI and more easily comparable between engagement groups. The main effects for ISI and engagement group and the ISI by engagement group interactions were expected to be similar to the results expected for the two-way analysis. With the inclusion of the block variable as a third independent variable to assess potential changes in performance stability during the continuation phase, I further expected that relative variability would increase over time specifically for participants in the passive engagement group at the longer ISI level (2000ms; see Figure 4)

The results from the three-way ANOVA are shown in Figure 8 and follow a similar pattern of statistical results as the previous two-way ANOVA tests. Only a significant main effect for ISI level was found ($F_{1, 153} = 24.957$, $p < .001$, partial $\eta^2 = .140$); the main effects for engagement group ($F_{1,153} = 0.274$, $p = .601$, partial $\eta^2 = .002$) and blocks[9] ($F_{2.744, 419.761} = 1.915$, $p = .132$, partial $\eta^2 = .012$) were not significant. The interactions between ISI level and engagement group ($F_{1, 153} = .630$, $p = .429$, partial $\eta^2 = .004$), ISI level and block ($F_{1.535, 234.841} = .898$, $p = .385$, partial $\eta^2 = .006$), and engagement level and block ($F_{2.744, 419.761} = .949$, $p = .411$, partial $\eta^2 =$, .006) were all found to be non-significant. Combining the ISI level, engagement group, and blocks variables together yielded a non-significant interaction between these three variables ($F_{1.535, 234.841} = 1.030$, $p = .342$, partial $\eta^2 = .007$).

[9] Degrees of freedom have been adjusted using the Greenhouse-Geisser correction for sphericity for any results that include the blocking variable.

Table 2.
Group-mean Differences for Coefficient of Variation in Three-Way Analysis

	500ms					2000ms				
Block	1	2	3	4	5	1	2	3	4	5
Active	.120	.064	.067	.089	.076	.114	.099	.138	.122	.193
Passive	.071	.080	.074	.128	.107	.149	.149	.148	.185	.174

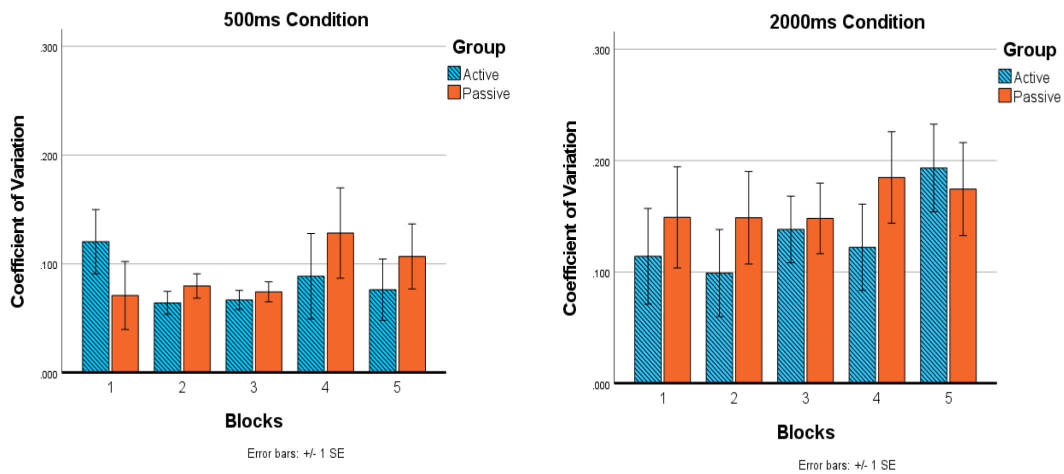

Figure 8. The group-mean differences in the coefficient of variation for ITI based on ISI level, block of continuation ITIs, and engagement level (500ms, left; and 2000ms, right).

CHAPTER IV

DISCUSSION

My goal in the current study was to determine whether there were differences in performance of a timing task depending on the type of engagement one has with the task. While an active engagement group was instructed to tap along with a metronome during the synchronization phase of a tapping task, a passive engagement group was instructed to only listen to the sound of the metronome during this phase. Both groups were then instructed to reproduce the tempo on their own in the absence of the metronome. Additionally, two different timing intervals were used for this study to determine if there were differences based on how much time there is between metronome beats. Overall, I expected that participants in the active engagement group would perform better on the timing task than the passive engagement group. However, the results of this study indicate that there were no statistically significant differences between engagement groups in terms of their timing performance and no interaction between engagement group and ISI level (500ms; 2000ms).

When comparing the engagement groups based on their mean ITI (Figure 5), both groups were seemingly able to internalize the target tempo during the synchronization phase and reproduce it similarly in the absence of the metronome during the continuation phase, regardless of whether they were instructed to tap along with the metronome (active engagement) or just listen to the metronome (passive engagement) during the synchronization. Although there were no statistical differences between engagement groups for mean ITI, the main effect of engagement group approached significance as the passive engagement group had longer ITIs on average than the active engagement group at both ISI levels. By analyzing only the mean ITI between groups, it could be concluded that one's level of task engagement may not matter when it comes to learning important aspects of the task; the mean ITI was about the same between the active and passive engagement groups (Table 1). However, an examination of just the mean ITI results may not provide the full picture.

Analyzing the standard deviation of the ITI as well provided information about participants' variability in timing performance and the stability of their internal representation of the target time interval. When comparing groups based on variability and using the coefficient of variation to standardize the standard deviation to the mean ITI (Figure 7), the active engagement group had a visibly lower coefficient of variation than the passive group. However, there were no statistical differences between groups in terms of variability as well as no interactions between engagement group and ISI level. These findings may indicate that the stability of the internal representation of the target interval was similar between engagement groups even though the information may have been encoded less strongly for the passive engagement group, which was only instructed to listen to the metronome. The absence of significant results for the standard deviation and coefficient of variation could be related to the high between-participants variability, as noted by the large error bars in Figures 6 and 7.

It was also of interest to examine whether the stability of the internal representation would change between groups as a function of the passage of time during the continuation phase. That assessment was accomplished by subdividing the number of ITIs during the continuation phase into five blocks of 20. An analysis of the coefficient of variation indicated that there were no significant differences between engagement groups as participants progressed through the continuation phase (Figure 8). For the 500ms condition, variability mostly increased as the continuation phase progressed as expected, but there were no significant differences between groups (Figure 8, left). Likewise, variability was higher for the 2000ms condition and again, mostly increased as the continuation progressed, but again, there were no statistical differences between engagement groups (Figure 8, right). Putting together these results and those previously mentioned may lead to the conclusion that regardless of the target timing interval, being more actively or passively engaged with a task may not matter for subsequent performance on the task. Both groups of participants used in this study achieved a similar stability of internal representations of the target interval, and participants' variability of these representations increased at seemingly equal rates as the continuation duration increased. Being more actively involved with the task did not allow for significantly better performance or lower variability than being more passively involved.

The findings of Held and Hein (1963) provided support for the idea that the coordination of perception and action in a given environment would lead to better performance on subsequent perceptual tasks than just using perception alone, which influenced the hypotheses for the current study. However, the results of the current study indicate overall that coordinating perception and action, as in the active engagement group, did not allow for significantly better performance than just acquiring information about the target interval through perception, as was the case in the passive engagement group. Even though both groups of participants were exposed to the same stimuli and virtual environment but interacted differently with the metronome during the synchronization phase, they were able to perform equally well on average during the continuation phase. Therefore, it would stand to reason that only being passively engaged in a task does not hinder one's ability to learn the important aspects of the task and perform worse than those who are more actively engaged with it. However, the main effect of engagement group on the mean ITI approached significance (p = .058) with the passive engagement group having had longer ITIs than the active engagement group (see Table 1). Although this result was not significant, it could indicate that those who only passively engaged with the task during the synchronization phase had more difficulty internalizing the target time interval, leading to longer ITIs and higher variability.

It seems reasonable to assume that the active engagement group would have had a better chance to encode the target timing interval more strongly than the passive engagement group because of the combination and coordination of perception and action during the synchronization phase. The active engagement had more physical practice and repetition than the passive engagement group to refine their perceptual abilities and maintain performance of the task (Seitz & Dinse, 2007; Shibata et al., 2014); whereas the passive engagement group was instructed to just listened to the metronome, the active engagement group was instructed to tap along with it. That reinforcement of the temporal information of the metronome through active engagement could have led to better and stronger encoding of the target time interval into memory. The active engagement group had shorter ITIs on average and lower variability than the passive engagement group, but these differences between groups were not statistically significant; having more physical practice during the synchronization phase did not significantly improve performance for the active group during the continuation phase.

Previous research has indicated that the ability to accurately tap in time with a metronome may occur more automatically at shorter timing intervals, while more conscious and deliberate attention may be needed at longer timing intervals (Miyake et al., 2004; Bååth et al., 2016). Just as attentional demands may change with ISI level, attentional demands could also differ between the active and passive conditions. Because the passive engagement group is not tapping with the metronome during the synchronization phase, they may have had to pay more attention to the metronome in order to perform just as well as the active engagement group when the metronome was turned off. Only perceiving the metronome without the coordinated motor response could have, then, strengthened the encoding of the temporal information and led to similar levels of performance between the active and passive engagement groups in terms of the mean ITI, which approached statistical significance. The strengthened encoding of the target interval by the passive engagement group could also be why there was an absence of significant differences between engagement groups in terms of variability; the internal representation of the target interval may have been stable enough across engagement groups to prevent one group from having a statistically higher variability than the other. Further research would need to be conducted to determine the role of attention in a timing task depending on whether participants are more actively or passively engaged with the task.

Generally, it appears that perception alone may be sufficient to learn a task and perform well following the familiarization period. Both groups of participants used in the current study were able to encode the temporal information of the metronome at both short and long timing intervals during the synchronization phase of a timing task and could perform equally as well on their own during the continuation phase without the guidance of the metronome. This finding could mean that for relatively simple interval timing tasks, like the finger-tapping task used in this study, just perceiving the task-relevant information can lead to performance quality levels equivalent to both perceiving the task-relevant information and acting in accord with it; active engagement may not result in superior performance over passive engagement in the synchronization-continuation paradigm.

Limitations and Future Directions

Data in the current study were collected remotely and online, which allowed for data collection from a large number of participants. However, there was little control over the experimental environment of each participant, such as the computer participants used or the time of day the study was completed. Between-participant variations in those factors may have contributed to the between-participant variation in the data (e.g. see error bars in Figures 6 & 7). Because participants completed the study remotely and on their own, it is impossible to determine whether participants adhered to all the instructions they were given, specifically in the passive engagement group: Participants in that group were instructed to "listen carefully to the metronome beats, keep their body still" and to begin pressing the spacebar after the sound of the metronome stopped (Appendix B). Although data analysis in the current study was limited to the continuation-phase performance, any taps made during the synchronization phase were recorded. There were a few participants in the passive group who made no more than three presses during the synchronization phase of both the practice and experimental conditions of the study (see Footnote 5 & 6 for specific details), but it is not clear what kind of influence those ITIs had on these participants' performance during the continuation phase. Further analysis of this dataset could be conducted to determine if those participants influenced the results of this study.

Additionally, even though participants in the passive group may not have recorded any spacebar presses during the synchronization phase, it is possible that participants might have engaged in other timing-related motor activities (e.g. engaging in toe- or foot-tapping). These unrecorded actions could have helped the passive participants internalize the tempo and perform like participants in the active engagement group. It would be of interest to repeat the current study in a more controlled, face-to-face laboratory environment, where experimenters could better control participants' compliance with the task instructions. Conducting an in-person experiment could provide an assessment of the validity of the current results, specifically that performance between the active and passive engagement groups did not differ statistically. Research has shown that studies replicated online yield results similar to those in the original face-to-face laboratory settings (e.g. see Yamanaka, 2022; Bartneck et al., 2015; Thomas & Clifford, 2017); however, most comparisons between these data collection methods have used participants recruited through Amazon's MTurk rather than a university participant pool, who may have different motivations and incentives for completing studies.

Additional limitations of this study were the age and experience of the participants as they were all undergraduate psychology students. Having a participant pool this young – the mean age was less than 20 years old for both experimental groups – makes it difficult to generalize these findings to the broader population. Including participants from older and younger populations could help identify any differences in timing performance as a function of age. Previous research has found that the ability to tap in time with a metronome improves with development from childhood into young and middle adulthood but tends to decrease going into older adulthood; older adults tend to have more variability in their timing performance (Thompson et al., 2015). However, an active engagement condition using only performance in the synchronization phase was used in that study (Thompson et al., 2015). Including a sample of younger and older populations with the active vs. passive design of the current study would allow researchers to determine what kind of effect engagement level has on subsequent timing performance across at different ages. If older adults have higher variability than younger adults using the traditional synchronization-continuation paradigm, perhaps including a passive condition would show even greater variability particularly at longer timing intervals. In addition, older adults who have more experience with timing behavior, such as musicians who continue to practice and perform as they get older, may not be as affected by the passive condition as their less experienced counterparts.

Because this was the first known study to assess timing performance differences under active vs. passive engagement levels, there are several other directions this research could go. First, during the synchronization phase in the current study, participants in the active engagement group had physical practice staying in time with the metronome whereas those in the passive engagement group did not. Varying the length of the synchronization phase (i.e., the number of ISIs) within each engagement group may yield different results and greater contrasts between groups than those found in the current study. In the current study, 20 ISIs were created by the metronome during the synchronization phase for both engagement groups at both ISI levels. Perhaps that number is too high to detect differences between groups because even those in the passive engagement group could internalize the tempi well. It could be that the advantage of the active engagement group through the coordination of the perceptual and motor information may only be statistically revealed when the synchronization phase contains fewer than 20 ISIs.

Second, people with different backgrounds and experiences may be able to time their actions better than the average person. For example, musicians may have to use different modalities – such as vision, audition, and action – when performing in time with the other members of their group (Love et al., 2012). The same could also be said for people who participate in team sports that need to work together to achieve a common goal. Previous research has shown that athletes may be better at emergent timing tasks while musicians may be better at event-based timing tasks (Janzen et al., 2014), but that study only used an active engagement condition. Participants in the current study completed a general musical sophistication inventory to assess their musical background and experience, although analyzing those data were outside the scope of this thesis. Examining those data could highlight any differences between musicians and non-musicians and their ability to time their actions based on their level of task engagement, and expanding this research to include athletes and non-athletes could show whether the type of previous experience matters for timing performance. Perhaps timing experts (such as those who are musicians and athletes and could have more practice with timing) would perform better than non-experts on a timing task like the one used for the current study, particularly for participants who would be in the passive engagement group.

Third, in the design of this study, participants in both the active and passive engagement groups went from the synchronization phase of the task directly into the continuation phase where they were asked to reproduce the target tempi in the absence of the metronome. Because of this design, those in the active engagement group continued to tap without any breaks between phases while those in the passive engagement group only started tapping when the continuation phase started. Besides the potential benefits the active engagement group gained through the pairing of perceptual and motor processes during the synchronization phase, they may have also had an advantage from the momentum they carried into the continuation phase by having had an early start on tapping. Those factors could have led to the active engagement group gaining a non-statistically significant advantage in their timing performance (Figures 5-8). An important next step in this line of research would be to add in a break between the synchronization and continuation phases so that participants would have to stop aligning their internal clock at the end of the synchronization phase, pause for a set period, and then attempt to reproduce the target interval during the continuation phase. This manipulation would remove the momentum of the active engagement group and would place both groups on equal footing at the start of the continuation phase, which could provide a better estimate of the operation of the internal clock as it relates to level of engagement. With the inclusion of this break, it would be interesting to see if the length of that break influences timing performance and specifically variability in performance. As the length of the pause increases, it could be that performance is poorer for the passive engagement group as the temporal information of the metronome may not be encoded as strongly as in the active engagement group.

Conclusion

In a finger tapping timing task, it was expected that those in an active engagement group who were instructed to tap along with a metronome during the synchronization phase of a timing task would perform better when reproducing the tempo of the metronome than those in a passive engagement group, who were instructed to only listen to the sound of the metronome during the synchronization phase. I predicted that the engagement and coordination of two different modalities, perception and action, would allow for stronger memory encoding of the target time interval, as compared to when just perceptual information processing was involved. However, those results were not found in the current study; instead, the findings revealed that, on the average, passive engagement was just as effective as active engagement. There were no significant between-group differences in variability; however, a non-significant advantage appeared for the active engagement group. Further research and analysis may be needed to determine whether these findings generalize to other situations, such as laboratory environments or different, more difficult tasks (e.g. varying the finger-tapping task as previously described or using a circle drawing task).

REFERENCES

Bååth, R., Tjøstheim, T. A., & Lingonblad, M. (2016). The role of executive control in rhythmic timing at different tempi. *Psychonomic Bulletin & Review*, *23*, 1954-1960. 10.3758/s13423-016-1070-1

Bao, Y., Pöppel, E., Wang, L., Lin, X., Yang, T., Avram, M., Blautzik, J., Paolini, M., Silveira, A., Vedder, A., Zaytseva, Y., & Zhou, B. (2015). Synchronization as a biological, psychological and social mechanism to create common time: A theoretical framework and a single case study. *PsyCh Journal*, *4*(4), 243-254. 10.1002/pchj.119

Bartneck, C., Duenser, A., Moltchanova, E., & Zawieska, K. (2015). Comparing the similarity of responses received from studies in Amazon's Mechanical Turk to studies conducted online and with direct recruitment. *PLoS ONE*, *10*(4), 1-23. 10.1371/journal.pone.0121595

Braun Janzen, T., Thompson, W. F., Ammirante, P., & Ranvaud, R. (2014). Timing skills and expertise: Discrete and continuous timed movements among musicians and athletes. *Frontiers in Psychology*, *5*, 1-11. 10.3389/fpsyg.2014.01482

Finger, H., Goeke, C., Diekamp, D., Standvoß, K., & König, P. (2017). LabVanced: a unified JavaScript framework for online studies. In *International Conference on Computational Social Science (Cologne)*, 1-3.

Flach, R. (2005). The transition from synchronization to continuation tapping. *Human Movement Science*, *24*, 465-483. 10.1016/j.humov.2005.09.005

Held, R., & Hein, A. (1963). Movement-produced stimulation in the development of visually guided behavior. *Journal of Comparative and Physiological Psychology*, *56*(5), 872-876.

Knief, U., & Forstmeier, W. (2021). Violating the normality assumption may be the lesser of two evils. *Behavior Research Methods*, *53*, 2576-2590. doi.org/10.3758/s13428-021-01587-5

Latif, N., Alsius, A., & Munhall, K. G. (2018). Knowing when to respond: The role of visual information in conversational turn exchanges. *Attention, Perception, and Psychophysics*, *80*, 27-41. 10.3758/s13414-017-1428-0

Love, S. A., Pollick, F. E., & Petrini, K. (2012). Effects of experience, training and expertise on multisensory perception: investigating the link between brain and behavior. In *Cognitive Behavioural Systems: COST 2102 International Training School*, Dresden, Germany, February 21-26, 2011, Revised Selected Papers (pp. 304-320). Springer Berlin Heidelberg.

Miyake, Y., Onishi, Y., & Pöppel, E. (2004). Two types of anticipation in synchronization tapping. *Acta Neurobiologiae Experimentalis*, *64*, 415-426.

Müllensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). The musicality of non-musicians: An index for assessing musical sophistication in the general population. *PLoS ONE*, *9*(2), 1-23. doi.org/10.1371/journal.pone.0089642

Petilli, M. A., Trisolini, D. C., & Daini, R. (2018). Sustained-paced finger tapping: A novel approach to measure internal sustained attention. *Frontiers in Psychology*, *9*, 1-6. 10.3389/fpsyg.2018.00881

Repp, B. H., & Steinman, S. R. (2010). Simultaneous event-based and emergent timing: Synchronization, continuation, and phase correction. *Journal of Motor Behavior, 42*(2), 111-126. 10.1080/00222890903566418

Seitz, A. R., & Dinse, H. R. (2007). A common framework for perceptual learning. *Current Opinion in Neurobiology*, *17*, 148-153. 10.1016/j.conb.2007.02.004

Shams, L., Wozny, D. R., Kim, R., & Seitz, A. (2011). Influences of multisensory experience on subsequent unisensory processing. *Frontiers in Psychology*, *2*, 1-9. 10.3389/fpsyg.2011.00264

Shibata, K., Sagi, D., & Watanabe, T. (2014). Two-stage model in perceptual learning: toward a unified theory. *Annals of the New York Academy of Sciences*, *1316*, 18-28. 10.1111/nyas.12419

Studenka, B. E., Cummins, D. L., & Pope, M. A. (2018). The role of multiple internal timekeepers and sources of feedback on interval timing. *Quarterly Journal of Experimental Psychology, 71*(9), 1960-1967. 10.1080/17470218.2017.1373835

Suzuki, M., Floreano, D., & Di Paolo, E. A. (2005). The contribution of active body movement to visual development in evolutionary robots. *Neural Networks, 18*(5-6), 656-665. 10.1016/j.neunet.2005.06.043

Thomas, K. A., & Clifford, S. (2017). Validity and Mechanical Turk: An assessment of exclusion methods and interactive experiments. *Computers in Human Behavior, 77*, 184-197. 10.1016/j.chb.2017.08.038

Thompson, E. C., White-Schwoch, T., Tierney, A., & Kraus, N. (2015). Beat synchronization across the lifespan: intersection of development and musical experience. *PLoS ONE, 10*(6), 1-13. 10.1371/journal.pone.0128839

Wing, A. M. (2002). Voluntary Timing and Brain Function: An Information Processing Approach. *Brain and Cognition*, *48*, 7-30. 10.1006/brcg.2001.1301

Wing, A. M., & Kristofferson, A. B. (1973). Response delays and the timing of discrete motor responses. *Perception & Psychophysics*, *14*(1), 5-12.

Woods, K. J. P., Siegel, M. H., Traer, J., & McDermott, J. H. (2017). Headphone screening to facilitate web-based auditory experiments. *Attention, Perception, and Psychophysics, 79*, 2064-2072. 10.3758/s13414-017-1361-2

Yamanaka, S. (2022). Utility of crowdsourced user experiments for measuring the central tendency of user performance: A case of error-rate model evaluation in a pointing task. *Frontiers in Artificial Intelligence, 5*, 1-12. 10.3389/frai.2022.798892

APPENDIX A

EXCLUSIONARY CRITERIA

An analysis into more potential outliers revealed no statistical differences between the dataset used in the current study and those that used the Interquartile Range (IQR) or Median Absolute Deviation (MAD) methods as exclusionary criteria (Table 3). The IQR method excluded participants who had mean ITIs more than 3 $\times$ IQR above the third quartile and more than 3 $\times$ IQR below the first quartile. The MAD method used the median ITI at each ISI level to find the median absolute deviations from the median. Participants were excluded using this method if they had a mean ITI that was more than 3 $\times$ MAD above the median and more than 3 $\times$ MAD below the median. Using these methods did not change the statistical significance of any result. All reported analyses and results were conducted using the dataset with 155 participants.

Table 3.
Differences in Significance across Exclusionary Methods

	Full Dataset	IQR Method	MAD Method
n	155	153	151
ISI (ME)	< .001	< .001	< .001
Group (ME)	.167	.413	.694
Interaction	.336	.607	.828

Note. Values reported in each cell represent the p-value of each main effect (ME) or interaction for each exclusionary method. (ISI = Inter-stimulus interval; IQR = Interquartile range; MAD = Median absolute deviation)

APPENDIX B

PARTICIPANT INSTRUCTIONS

When completing the tapping task used in this study, participants in the active engagement group were instructed to press the spacebar in time with the metronome they heard during the synchronization phase of the paradigm at both ISIs, and participants were then instructed to continue tapping at the same interval they heard in the absence of the metronome during the continuation phase. The slide on the top of Figure 9 is the set of instructions participants received after adjusting their seating and audio levels if needed. The slide on the top of Figure 10 is the set of instructions participants received directly before beginning the experimental conditions, repeated for each ISI level (500ms and 2000ms).

Conversely, participants in the passive engagement group were instructed to just listen to the metronome during the synchronization phase of the paradigm while keeping their body still, and participants were then instructed to begin tapping at the same interval they heard in the absence of the metronome during the continuation phase. The slide on the bottom of Figure 9 is the set of instructions participants received after adjusting their seating and audio levels if needed. The slide on the bottom of Figure 10 is the set of instructions participants received directly before beginning the experimental conditions, repeated for each ISI level (500ms and 2000ms).

Instructions for Experimental Phase:

• **First,** you will hear a series of metronome beats. Please **(a) listen carefully to the metronome beats, (b)** keep your body still, and **(c) press the *SPACE BAR*** using the *index finger of your dominant or preferred hand* so that your presses **occur at the same time as (coincide with) the metronome *BEAT***.

• **Second,** after a certain number of metronome beats, the sound of the metronome will cease.

• **Third,** although the sound of the metronome has ceased, **continue pressing the *SPACE BAR*** so your presses occur at the same time as (coincide with) the metronome beat, as if the metronome beat was still present. Continue performing until the condition ends.

There will be a total of 2 experimental conditions that will each be longer than the practice condition.

Instructions for Experimental Phase:

• **First,** you will hear a series of metronome beats. Please **(a) listen carefully to the metronome beats, (b)** keep your body still, and (c) rest the *index finger of your dominant or preferred hand* on the SPACE BAR but do **NOT press the SPACE BAR**.

• **Second,** after a certain number of metronome beats, the sound of the metronome will cease.

• **Third,** once the sound of the metronome has ceased, please **begin pressing the *SPACE BAR*** so that your presses occur at the same time as (coincide with) the metronome beat, as if the metronome beat was still present. Continue performing until the condition ends.

There will be a total of 2 experimental conditions that will each be longer than the practice condition.

Figure 9. The set of instructions participants received after adjusting their seating and audio levels (active group, top; passive group, bottom).

In a moment, an experimental condition will begin!

• Focus your attention on the center of the screen.
A **fixation cross (+)** will appear ***1 second*** before the first metronome beat.

• ***Be prepared*** to press the ***SPACE BAR*** with the ***index finger of your dominant or preferred hand*** so your presses **occur at the same time as the metronome *BEAT***.
Your ***first press*** should coincide with the ***first beat***.

•When the sound of the metronome has ceased, **continue pressing the *SPACE BAR*** so your presses occur at the same time as the metronome beat as if the metronome beat was still present.

•Continue performing until the condition ends.

In a moment, an experimental condition will begin!

• Focus your attention on the center of the screen.
A **fixation cross (+)** will appear ***1 second*** before the first metronome beat.

• ***Be prepared*** to press the ***SPACE BAR*** with the ***index finger of your dominant or preferred hand***.

•When the sound of the metronome has ceased, **begin pressing the *SPACE BAR*** so your presses occur at the same time as the metronome beat as if the metronome beat was still present.
Your ***first press*** should occur ***AFTER*** the metronome beat has ceased.

•Continue performing until the condition ends.

Figure 10. The set of instructions participants received before beginning each experimental ISI condition (active group, top; passive group, bottom).