Tapping Behavior and Inter-Stimulus Interval in Isochronous Sound Sequence

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Abstract: The main objective of this study is to examine anticipatory tapping and reactive tapping under two different inter-stimulus interval (ISI). Healthy participants (N = 30) aged from 18 to 35 years voluntarily participated in the study. The results show that the ISI plays an important role in sensory motor synchronization (SMS). The analysis of asynchrony revealed that two different type of tapping occurred under two different ISI. Under short ISI (1000 ms), participants executed their responses before the tone (i.e., anticipatory tapping driven by feed-forward motor control). Under long ISI (2000 ms), participants executed their responses after the tone (i.e., reactive tapping driven by feedback motor control mechanism). In summary, participants showed anticipatory tapping in the absence of top-down attention and reactive tapping with the involvement of top-down attention.

Keywords: Anticipatory Tapping, Feedback motor control, Feed-forward motor control, Inter-stimulus Interval, Reactive Tapping.

I. INTRODUCTION

Sensory-motor synchronization (SMS) refers to the rhythmic coordination between perception and action [36]. For instance, people move their body parts in response to musical beats in which actions are coordinated in the prediction of an external event [31]. It is important to have situation where both action and referent are periodic for SMS to occur [32]. This is because periodicity of the referent increases its predictability where referent refers to auditory stimuli in a sequence comprises of series of auditory stimuli. Therefore, SMS requires temporal coordination between motor rhythm and external auditory rhythm [35]. In the context of Rhythmic auditory stimulation (RAS), Thaut and Abiru [43] have shown that auditory rhythm affects the motor system because both systems share crucial connectivity at cortical, subcortical, and spinal level.

Auditory system plays an important role in processing temporal information quickly and precisely in order to pass it to motor structures in the human brain, thus creating synchrony between rhythmic sound sequence and motor response (such as tapping in this study) [23]. This study highlights two aspects of asynchrony with respect to execution of tapping response. When individuals try to synchronize their tapping with the sound sequence, it is necessary to predict the next stimuli from the current state. Often in anticipation of the next event, individuals usually tap before the incoming event referred to as negative asynchrony.

In contrast, positive asynchrony occurs with the involvement of top-down attention because it activates the feedback motor control system which is a reflexive motor action and it leads to reactive tapping.

The primary goal of the current study was to investigate the anticipatory tapping and reactive tapping in isochronous sound sequence under short ISI and long ISI levels. An important concern with respect to the role of temporal aspect is that of understanding how ISI affects SMS. Miyake, Onishi, and Pöppel [27] reported that there is different levels of involvement of attentional demand under ISI range of 1800-3600 ms and ISI range of 450-1500 ms such that the former is found to have more attentional demand.

As the ISI range of 450-1500 ms demands lesser attentional resources, this ISI range will switch motor control to feed-forward mode because it doesn’t require voluntary control [20][39]. In the feed-forward model of motor control, cerebellum receives an efferent copy (internal copy of an efferent movement inducing signal) of a motor command from the primary motor cortex for a motor-to-somatosensory prediction [25]. This, in turn, induces the cerebellum to make predictions about the sensory consequences of these motor instructions, which prepares the muscle-skeletal system for movement execution. Incoming sensations are then contrasted with the predicted sensations. A constructive match between incoming and predicted sensation also maintains the same pattern for the succeeding motion. This whole process leads to anticipation.

In the long ISI range of 1800-3600 ms which is also called the supra-second range involves more attentional demand which activates feedback motor control system [14][21][42]. Seidler, Noll, and Thiers, [39] performed a study in which people had to hit objects with different size on the LCD screen with a moving joystick and found that movement responses to larger targets relied more on feed-forward-motor control whereas movement responses to smaller targets relied on feedback motor control. Smaller targets require more attention than larger targets due to increased precision requirements for aiming.

In the light of the current discussion, it is conceivable that temporal aspect of ISI will play a role in SMS (tapping performance). The point is that if the involvement of attention is different in two different ISI namely, short ISI and long ISI they are expected to have significant difference in terms of SMS. As anticipation happen when there is lesser involvement of attention. So it is expected that anticipatory tapping will happen under short ISI whereas reactive tapping will happen under long ISI.

II. MATERIALS AND METHODS

Participants performed the experimental task that required them to tap on tapping board with their dominant index fingers in response to the tone present in isochronous sound sequence. The tone occurred 72 (i.e., 2 initiation tones + 70
execution tones) times in both ISI levels out of which first two tones were initiation tones whereas the remaining were execution tones. Investigators created two isochronous sound sequence with the help of Audacity software [26], under two different ISI, i.e., (i) Short ISI (1000 ms), (ii) Long ISI (2000 ms). The duration of isochronous sound sequence was 7 minutes under short ISI and was 14 minutes under long ISI (i.e., double the duration of short ISI). This duration does not include initiation period in which 2 initiation tones were presented i.e., 2 seconds and 4 seconds in short ISI and long ISI respectively. As stated above, there were 70 occasions of presenting the execution tone to which participants were required to tap in a synchronized manner (i.e., tapping needs to be coincide with the presentation of the execution tone). In order to maintain steady intensity, participants used noise-cancellation headphones (68 SPL) during the experimental task. That also used Disposable Head cap considering hygiene. For measuring the tapping response, the investigators used Arduino based customized tapping board. This Arduino based tapping board was customized (developed for this study) to synchronize with the PC via a light-dependent resistor, which was placed over the lower right corner of the PC screen to ensure synchronization of tapping data with the execution tones. Tapping data were recorded using Arduino based customized tapping board connected to a Dell PC running Arduino IDE software; light-dependent resistor was placed on the lower right corner of the PC screen to achieve synchronization between tapping board and PC.

A. Design
The study was a between-groups design with ISI having two levels (Short ISI vs. Long ISI). The Short ISI and Long ISI response were differentiated by varying temporal interval between the offset of one stimulus to the onset of another in Isochronous Sound Sequence. In Short ISI level, there was a tap to the onset of another as compared to Long ISI level which had a fixed interval of 2000 ms.

B. Arduino Tapping Board Set-up
Piezoelectric sensor was connected to pin 1 of an analog port of Arduino microcontroller for measuring tapping data. LDR sensor’s output was fed to pin 0 of an analog port of arduino microcontroller for synchronization with PC. Investigators placed LDR sensor over the lower right corner of the PC screen. In this arduino tapping board set-up, audio metronome starts with the start of the black screen which is detected by LDR. This generates start signal which received through analog pin 0 and by receiving this signal, it starts taking tapping data through analog pin1.

C. Procedure
Prior to engaging the participants, the investigators secured the approval of the experimental protocol from the Institute Human Ethics committee, Discipline of Biosciences and Biomedical Engineering which monitors the ethics compliance issues. Participants were explained about the task that they had to perform in the experiment so that they could take an informed decision regarding their consent. After this, a vital information sheet for recording personal details (such as, name, date of birth, interest in music etc.) was used by the experimenter.

Practice session preceded experimental task for each participant in order to ensure that they had understood the task. Each participant was engaged individually for the experimental session. The experimenter sat beside the participant (Fig. 1) for empirical observation through a parallel headset connected to the audio splitter. After data collection, participants went through a debriefing session in which each participant was asked some probing questions about his/her experience during the experiment.

![Fig.1.Experimental Set-up](image)

III. RESULT
Anticipatory tapping and reactive tapping: Anticipatory tapping and reactive, tapping are examined in terms of asynchrony of tapping responses (i.e., negative and positive asynchrony). Negative asynchrony and positive asynchrony are differentiated in terms of the nature of taps with reference to deviation from exact coinciding point. In other words, the sign of asynchrony is determined based on whether a tap is executed before or after the occurrence of the tone. For instance, those taps which occur before the tone will be considered as negative asynchrony in contrast to positive asynchrony i.e., taps which occur after the tone.

A paired-sample t-test was performed to compare anticipatory tapping and reactive tapping under the short ISI (1000 ms) in terms of their occurrences. The analysis revealed a significant difference between anticipatory tapping (M = 59.5, SD = 24.27) and reactive tapping (M = 12.4, SD = 24.27); t(14) = 3.75, p = 0.002, two-tailed. Further, an independent-sample t-test was performed to compare anticipatory tapping between short ISI and long ISI. There was a significant difference with respect to anticipatory tapping between short ISI (M = 59.5, SD = 24.27) and long ISI (M = 22.66, SD = 25.53); t(28) = 2.537, p = 0.017<0.05, two-tailed. Further, an independent-sample t-test revealed a significant difference in reactive tapping between short ISI (M = 12.46, SD = 24.27) and long ISI (M = 49.33, SD = 25.53); t(25) = -2.35, p = 0.023<0.05, two-tailed. Fig. 2 shows anticipatory tapping and reactive tapping under both ISI levels. On the whole, the results provide statistical evidence that there is higher occurrence of anticipatory tapping under short ISI as compared to long ISI. In comparison, higher occurrence of reactive tapping is observed under long ISI than short ISI. Fig. 3a and Fig. 3b show the asynchrony variation of participants for all the 70 occasions under short ISI and long ISI respectively. In both the figures 3a and 3b, line plots below 0 (which is ref line)
represents negative asynchrony and line plots above 0 represents positive asynchrony. Thirteen participants showed anticipatory tapping in terms of negative asynchrony and only two participants showed reactive tapping in terms of positive asynchrony under short ISI.

In case of short ISI, individuals tend to tap before the onset of the tone by anticipating it, instead of tapping in a symmetric uniform distribution around original (irregular) stimuli [36][31][3-5][12][45]. Therefore, investigators conclude that anticipation plays an important role in the short ISI to predict the next event while synchronizing with the external event. Anticipation happens in the absence of required attentional resources. It conforms to the understanding that lesser attentional demand is required in the short ISI [27]. In this context, a relevant issue is in terms of how anticipation takes place when there is a lesser involvement of top-down attention. The point is anticipation takes place when activities rely not only on previous and present stimuli but also on future projections, expectations, or beliefs [38]. Therefore, the current study indicates that the role of sequential decision making becomes very important in synchronizing with the tones present in isochronous sound sequence and anticipation is a critical part of this process.

In sequential decision making, individuals make decisions based on anticipation involving memory (i.e., retrieval of information by attractor dynamics if a given input is sufficiently similar to a stored attractor state)[2]. During decision making between sequential auditory stimuli, the first stimulus is held in memory and then compared with the subsequent similar stimuli. Attractor neural activity of second stimuli depends not only on the present stimuli but also on the sensory memory of the first sound event[10]. Anticipation cannot happen without memory because as it plays an important role in prediction [15] and it gives the previous experience to the individual for anticipation of the next stimulus from its current state. Auditory sensory memory is the shortest element of memory and the critical first stage in auditory perception [1]. It gives the cognitive system to retain representations of sensory information after the previous auditory stimuli have ended. It acts as a buffer for the stimuli received through auditory senses, which is very briefly (but accurately) retained. In case of short ISI, next stimulus occurred before the decaying of sensory memory, so this past sensory memory helped to predict the next event via anticipation mechanism and the ‘prediction’ is a preplanned behavior that activates the feedforward motor control mechanism and it is unaffected unaffected by peripheral feedback[30]. Feed-Forward motor control is an open-loop system for motor control that controls fast, ballistic movements before any sensory information is processed [39][17]. It requires prior knowledge of the upcoming stimulus. For this type of control, deafferentation studies have been done on monkeys and cats whose sensory nerves were cut off from their spinal cords [41]. After recovering from the deafferentation procedure, monkeys started normal behavior after losing sensory information from their arms. That is why this motor control mechanism is called ‘automatic’.

In this automatic mechanism, some reflex loops require lower brain areas and are independent of perceptual processing active control but can be affected by prior commands; while the other loops are directed by the spinal cord with no active control of the brain.

In case of long ISI, participants showed reactive tapping behavior. Reactive response is a reflexive response which is not based on anticipation. It is because of memory traces decline (i.e., decaying) over a short span of time until a certain limit is reached, and that memory becomes unreliable[28][7].

IV. DISCUSSION

This study emphasizes the issues pertaining to SMS in isochronous sound sequence. ISI is an important aspect concerning response asynchrony.

As per the results, the dominance of anticipatory tapping over reactive tapping under short ISI implies the predictive quality of a synchronized motor action with an anticipated stimulus [36][31][3-5] unlike long ISI. On the other hand, higher occurrence of reactive tapping under long ISI as compared to short ISI indicates a reflex activity. This occurs in reaction to a stimulus associated with feedback motor control relying on sensory feedback for coordinating movements [17].

Fig. 3a. Asynchrony variation under short ISI (execution tones)

Fig. 3b. Asynchrony variation under long ISI (execution tones)

It implies that anticipatory tapping is more prevalent in short ISI and Fig. 3b shows that participants showed both reactive and anticipatory tapping because none of these two was prevalent in long ISI. But there were more number of cases for reactive tapping in long ISI as compared to short ISI.

Fig. 2. Anticipatory Tapping and Reactive Tapping under Short and Long ISI

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Under such circumstances, it becomes difficult for an individual to retain representation of auditory information for a longer duration because memory decays very quickly, in the region between 200-500 milliseconds (less than a second) [24]. Moreover, in the absence of anticipation mechanism, top-down attention plays a critical role which switches an individual’s motor action to feedback mode (in contrast feed-forward mode) for error compensation. In other words, feedback motor control relies on sensory feedback for coordinating movements. Reactive tapping is a reflex activity which occurs in reaction to a stimulus due to feedback motor control. As reactive tapping in long ISI (2000 ms) occurs under supra-second range and anticipatory tapping in short ISI (1000 ms) occurs in 1-second range, it indicates that as the ISI increases from 1-second to supra-second range, there is a transition in tapping from anticipatory to reactive.

In future studies, it will be important to examine issues concerning sensory-automatic processing in 1-second range which is a transit zone [33-34] between sub-second range and the supra-second range.

V. CONCLUSION

In summary, this study demonstrates significant occurrence of anticipatory tapping and reactive tapping under short ISI (1000 ms) and long ISI (2000 ms) respectively. In Anticipatory tapping, the feed-forward motor control mechanism plays a critical role (unlike the case of reactive tapping in which the motor control is dependent on the feedback motor control mechanism). In terms of implications, the findings of this study indicate that ISI in isochronous sound sequence should be given due consideration in designing movement studies and incorporate use of the same for therapeutic purposes such as rhythm auditory stimulation (RAS).

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REFERENCES


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