

Investigating the Impact of Inter-Stimulus Delay on Temporal Processing

A

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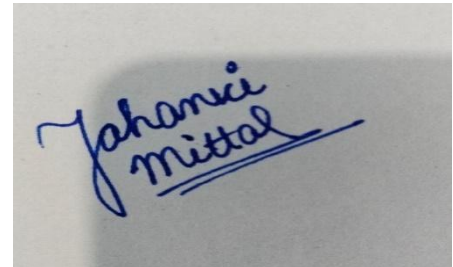
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CERTIFICATE

This is to certify that the thesis entitled, "*Investigating the Impact of Inter-Stimulus Delay on Temporal Processing*" is being submitted in partial fulfillment of requirements for the award of the degree of **Master of Arts in Psychology**, submitted in the **Thapar School of Liberal Arts & Sciences, Thapar Institute of Engineering and Technology, Patiala**. This is a bonafide work carried out under the supervision of Dr. Anuj Kumar Shukla, at Thapar School of Liberal Arts & Sciences, Thapar Institute of Engineering and Technology, Patiala and that no part of this thesis has been submitted for the award of any other degree.



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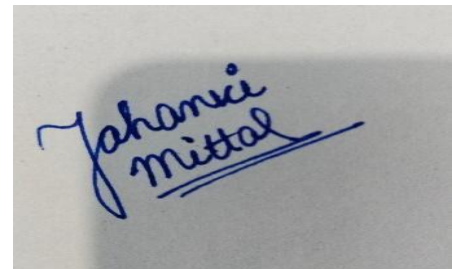
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CANDIDATE'S DECLARATION

I hereby declare that the work presented in this thesis entitled "*Investigating the Impact of Inter-Stimulus Delay on Temporal Processing*" is being submitted in partial fulfillment of requirements for the award of the degree of **Master of Arts in Psychology**, presented in the **Thapar School of Liberal Arts & Sciences, Thapar Institute of Engineering and Technology, Patiala** is an authentic record of my own work carried out under the supervision of **Dr. Anuj Kumar Shukla**, at **Thapar School of Liberal Arts & Sciences, Thapar Institute of Engineering and Technology, Patiala** and refer other researchers' work which are duly listed in the reference section. The matter written in this thesis has not formed the basis for awarding any other degree at this or any other university.



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This is to certify that the above statement made by the student concerned is correct and true to the best of my knowledge.



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"Teaching is more than imparting knowledge; it is inspiring change, " said William Arthur Ward & learning is more than absorbing facts; it is acquiring understanding.

As I sit down to express my gratitude, I am filled with a sense of appreciation for my guide and supervisor Dr. Anuj Kumar Shukla who had a profound impact in my life. His unwavering commitment to education and his students is truly inspiring. His enthusiasm for niche fields like 'Time Perception' is contagious and it has ignited a spark within me for learning various aspects of this field that I never knew existed. His patience and understanding have made a significant contribution in my academic journey, especially working with him in dissertation. I could see both my imperfections and perfections and understood what it means to let growth in and what it means to let experiences impart useful knowledge.

He was the one who pushed me to test my limits. I am grateful for his hard work, the hours that he put in and the way he treated me with so much respect. He told me about his failures, and his successes and for some reason, it all resonated with me and I started to realize that anything really is possible.

I would also like to thank all the participants who took part in my experiments and made this research possible. Without their time and dedication towards my experiments, the study would not have been possible.

ABSTRACT

Time is a universally fundamental concept studied by psychologists, neuroscientists, and philosophers, yet the field of time perception remains not fully understood. In experimental lab settings, Interstimulus Interval (ISI) is a critical factor during the presentation of stimuli. Researchers across various fields, including attention, perception, and memory, typically vary ISI to avoid inherent learning effects that might skew results. However, it remains unclear how variations in ISI affect temporal processing. This raises important questions about the influence of interstimulus delay on temporal judgment and sensitivity.

To address these questions, we adopted a temporal discrimination paradigm where a standard stimulus is followed by a comparison stimulus. Instead of keeping ISI constant, we manipulated ISI to two different durations: 500 ms (short) and 1000 ms (long).

We conducted two studies, each comprising two experiments. In Study 1, we examined the influence of varied ISI on temporal judgment in visual and auditory discrimination tasks. For the visual discrimination task, data were obtained from 35 participants, each performing 182 trials. The findings revealed significant differences in the Point of Subjective Equality (PSE) between short and long ISIs, suggesting an overestimation for long ISI and underestimation for short ISI. Statistically significant differences in the Difference Limen (DL) were also observed for both ISI conditions. In the auditory discrimination task, data were gathered from 28 participants, each performing 168 trials. The results were consistent with the visual task, showing low PSE (overestimation) for long ISI and high PSE (underestimation) for short ISI. However, no statistically significant differences in DL were found for auditory tasks.

In Study 2, we investigated how variations in ISI affect emotional context-dependent temporal processing. Experiment 1 involved 22 participants, each performing 196 trials, with standard and

comparison stimuli presented for different durations. The findings mirrored those of Study 1, indicating temporal dilation for long ISI and temporal compression for short ISI, with no significant differences in DL. Experiment 2 involved 38 participants, each performing 196 trials, with both standard and comparison stimuli presented for the same durations. We analyzed the proportion of long responses (p-long) for each duration under two conditions (short vs. long delay). A 2x7 repeated measures ANOVA (Delay: Short ISI vs. Long ISI; Durations: 200 ms to 800 ms) showed significant main effects for both duration and delay, but no interaction effect.

Overall, the findings suggest that varying ISI influences temporal judgment. Both short and long ISIs affect perceived duration, supporting aspects of prominent cognitive models such as the Internal Clock Model and the Attentional Gate Model. However, these models only partially explain the timing mechanisms observed, indicating that brain-level processes must also be considered.

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CHAPTER 1

1.1 INTRODUCTION & LITERATURE REVIEW

Time is a finite yet invaluable asset that impacts every aspect of human life. Our experience of time is highly subjective; it seems to drag when we're feeling down but flies by when we're enjoying ourselves. This perception is influenced by our activities and mental engagement at any given moment. The more thoughts we have in a period, the longer it feels, whereas fewer thoughts make time seem shorter (Sturt, 1925).

The study of how we perceive time, known as Time Perception, is a key area in psychology. The term was first introduced by E.R. Clay in 1882 and further developed by William James. Time perception is crucial to human existence and underlies all our activities (Matthews & Meck, 2014). Whether attending a tedious lecture, having a meaningful conversation, cooking, or sculpting, our sense of time is always engaged.

Various factors influence our subjective experience of time, including age and general intelligence (Bartholomew et al., 2015), body temperature (Wearden & Penton-Voak, 1995), clinical conditions (Allman & Meck, 2012; Vataakis & Allman, 2015), sex differences (Block et al., 2000; Hancock & Rausch, 2010), and developmental changes (Block et al., 1999; Droit-Volet, 2012; Droit-Volet & Zelanti, 2013; McCormack, 2015). We have five senses—vision, hearing, touch, taste, and smell—that help us perceive the world around us. However, we don't have a specific sense organ for perceiving time. Instead, psychological time is an abstract construct created by our minds to make sense of our experiences (Grondin, 2001, 2010a, 2010b; Callender, 2010; Macar & Vidal, 2009; Allman, Yin, & Meck, 2014). This makes it difficult to be aware of how others perceive time. To study this phenomenon, researchers use various methods to understand how people perceive and judge the passage of time.

Studies of time perception are categorized into two types: prospective and retrospective temporal judgment. In prospective judgment, participants know beforehand that they need to estimate duration. In retrospective judgment, participants estimate duration after the event has occurred. Essentially, prospective timing involves judgments about future events, while retrospective timing involves judgments about past events.

Researchers use different paradigms to study these processes, such as temporal bisection, temporal discrimination, temporal generalization, and temporal reproduction. Various models attempt to explain the effects observed in these paradigms when independent variables are manipulated to determine their impact on dependent variables.

One influential theory is Treisman's Internal Clock Model (1963). This model proposes a hypothetical pacemaker that produces regular pulses, the rate of which depends on the person's level of arousal. Higher arousal generates more pulses, while lower arousal generates fewer. Treisman distinguishes between general arousal (internal events) and specific arousal (external events). Pulses from the pacemaker are accumulated in a cognitive counter. When an event starts, a switch closes, allowing pulses to transfer from the pacemaker to the counter. When the event ends, the switch opens, stopping the pulse transfer. This model states if more pulses are accumulated in the counter, there will be an overestimation of duration and if less pulses are accumulated in the cognitive counter, underestimation of the duration will be observed.

The other model is a modification to the internal clock model which says that a person can divide his/her attention towards temporal properties and non-temporal properties (Thomas & Cantor, 1975; Thomas & Weaver, 1975). This model assumes that attention must be paid to an event for the pulses to be transferred to the cognitive counter and these pulses are modulated by two factors. Two key factors that influence our perception of time are arousal levels and the latency of the

cognitive "gate" mechanism. The general (internal) and specific (external) arousal induced by an event can affect how time is perceived. High arousal levels can make time seem to pass more quickly or slowly depending on the context. Another crucial factor is the latency of the gate that controls the flow of pulses from the pacemaker to the cognitive counter. This latency can determine whether time feels subjectively longer or shorter. When the gate opens or closes more quickly, it can lead to a perception of time passing more slowly (overestimation) or rapidly (underestimation) (Block & Zakay, 1996).

The current study makes use of conventional psychophysical tools i.e. employing temporal discrimination tasks in which a standard stimulus with a fixed duration across trials followed by a comparison stimulus with variable durations is presented to the participants. They have to judge whether the comparison stimulus lasted longer/shorter than the standard stimulus. It is important to note that previous studies have used this paradigm to examine various aspects of temporal processing such as perception of time intervals, temporal integration and temporal segmentation. However, this study has also used discrimination tasks to investigate the impact of varied Inter-stimulus intervals on temporal judgments.

In their 2009 study, Buonomano and his colleagues examined how the gap between stimuli, known as the interstimulus interval (ISI), affects our ability to perceive time accurately. They found that while the ISI influences our precision in discriminating between time intervals, it doesn't alter our subjective perception of time itself. Their investigation comprised three experiments, all centered on auditory perception. In the first experiment, participants were tasked with comparing intervals where the standard interval matched the comparison interval. In the second experiment, participants compared intervals where the standard interval differed from the comparison interval. The third experiment introduced a learning component to examine how practice influenced

performance. Throughout these experiments, the researchers tested both the same and different frequencies for the standard and comparison intervals, leading to four distinct conditions: short ISI, same frequency; long ISI, same frequency; short ISI, different frequency; and long ISI, different frequency. Their findings revealed that while the accuracy of timing judgments was indeed influenced by the ISI and the frequency of the intervals, there was no perceptible shift in the point of subjective equality (PSE). This suggests that participants didn't consistently perceive durations as longer or shorter; rather, they struggled more with accurately judging the timing.

Additionally, the study explored whether practice could enhance performance. Interestingly, they observed that training on either short or long ISIs resulted in different patterns of improvement, suggesting that learning and temporal engagement varied depending on the specific timing conditions.

In another study conducted by Karmarkar and Buonomano (2007), the researchers aimed to test a prediction made by the State Dependent Network Model (SDN). This model suggested that performance would be impaired when the state of the network during the target time varied across trials. To test this prediction, the researchers employed a two-interval forced choice procedure. They varied the interstimulus interval (ISI) for two durations: 250 ms and 750 ms. This experiment was conducted exclusively in the auditory modality. Participants were tasked with comparing whether a comparison stimulus lasted longer or shorter than a standard stimulus. The results of the study indicated a decrease in performance in the short ISI conditions compared to the long ISI conditions. This decrease in performance was explained by the SDN model. According to the model, in the short ISI conditions, the network failed to return to its initial state, resulting in poor discrimination abilities. Although previous studies have explored the influence of interstimulus interval (ISI) on temporal processing, the exact mechanisms remain unclear. Moreover, the

mentioned studies primarily focused on auditory stimuli with short time ranges, typically within 200 ms. This limitation makes it difficult to generalize the findings to other sensory modalities and longer time intervals. Therefore, it is essential to investigate the influence of ISI in different modalities, such as vision, and with longer time ranges above 200 ms to determine the broader applicability of the previous results. Based on prior research, it appears that impairment occurs with short ISI but not with longer ISI. However, it is important to verify whether this effect persists across different modalities. To the best of our knowledge, studies that vary ISI have been conducted exclusively in the auditory domain, leaving it unknown how temporal judgment performance might be affected by varied ISI in the visual domain. The present study aims to address this gap by investigating the influence of varied ISI across different contexts and modalities. This research will help determine if the observed effects in auditory processing are consistent in visual processing and other time ranges, thereby enhancing our understanding of temporal processing mechanisms.

CHAPTER 2

TIME & DELAY: INFLUENCE OF DELAY ON TEMPORAL JUDGMENT

2.1 INTRODUCTION

Time is an integral part of our lives. Without time, human existence is not possible but there is a debate about how humans estimate time and then to explain that experience has always been a challenge for everyone. In time perception, major research has been done on the estimation of duration and it has been a fascinating aspect to investigate with. Duration estimation refers to the ability to approximate time that has been progressed between two events by using units of time such as milliseconds, seconds, minutes or hours. If duration estimation seems to occur for a longer period, it is because of the greater amount of content being stored and estimation of duration for short intervals accounted for less information being processed by us (Pöppel, 1978). Thus, the perception of time is an important part of our day-to-day activities, affecting our behavior and necessary for our survival (Pöppel, 1997; Wittmann, 1999; Buhusi & Meck, 2005). On reviewing the literature, it has been found that perception of time gets affected by a lot of factors such as number (Chang et al., 2011; Skagerlund et al., 2016; Shukla & Bapi, 2021, 2022), music (Mittal et al., 2024; Rammsayer & Altenmüller, 2006; Parsons, 2001), color (Shibasaki & Masataka, 2014; Ioan et al., 2007), substance use (Tinklenberg et al. 1976), emotion (Effron et al., 2006; Smith et al., 2011), memory (Sharot & Phelps., 2004; Mather, 2007) and attention (Vuilleumier, 2003; , Ledoux, 1996, 2012).

In time perception experiments, both stimulus properties (such as emotion, color, and music) and non-stimulus properties (such as task difficulty, age, gender, cognitive abilities, and individual characteristics) influence our temporal judgment. For example, we tend to overestimate the

duration when we are waiting for someone. Conversely, we may underestimate the duration, when we are having fun with friends and family. Furthermore, time seems to pass more slowly when there are fewer events, but when many events happen simultaneously, we often perceive time as passing more quickly (Bae & Kim, 2014).

Despite extensive research, it remains unclear how variations in time perception experiments lead to underestimation or overestimation of duration (Oliveri et al., 2008; Cai & Wang, 2014; Tipples, 2011; Mella et al., 2011; Shukla & Bapi, 2022). While time is a fundamental aspect of our experiences, the mechanisms behind these perceptual variations are not yet fully understood. Also, it is important to understand that there are limited studies that vary the delay between the two stimuli and study its effect systematically. Thus, the objective of this study is to investigate how varying the Interstimulus Interval (ISI) affects temporal judgment in visual and auditory tasks. The primary motivation behind this research was to understand how changes in ISI can lead to differential temporal processing. To explore this, we used both visual and auditory temporal discrimination paradigms. In these paradigms, a standard stimulus of fixed duration was followed by a comparison stimulus of varying durations. We varied the ISIs, defining 500 ms as short and 1000 ms as long. Our goal was to examine the effect of ISI in both visual and auditory modalities, testing how varying delays in these different contexts influence temporal judgment.

EXPERIMENT 1: VISUAL TEMPORAL DISCRIMINATION TASK

2.2 MATERIALS AND METHOD

2.2.1 PARTICIPANTS

A total of 35 participants were recruited from Thapar Institute of Engineering and Technology, Patiala, Punjab, India in the age range of 18-30 years. The experimental procedures and methodologies adhered to guidelines and regulations and this study got approval from the Institute Review Board (IRB) at Thapar Institute of Engineering and Technology, Patiala, Punjab, India. Informed consent was obtained from all the participants before the conduction of the experiment. None of the participants reported any visual impairment.

2.2.2 APPARATUS

The presentation and control of stimuli were administered using *OpenSesame* stimulus presentation software (Mathôt et al., 2012). The stimuli were displayed on a 17-inch CRT monitor (1024 × 768 resolution) operating at a frame rate of 100 Hz.

2.2.3 STIMULUS

The experiment began with the fixation cross presented at the centre of the screen. In the visual temporal discrimination task, a black square measuring 2 degrees of visual angle was presented against a white background. Participants were asked to press the spacebar to start the experiment and were shown a black square as the standard stimulus with a fixed duration of 500ms followed by a comparison stimulus (black square) presented with seven objective durations ranging from 200 to 800ms. A blank screen as an Interstimulus Interval (ISI) was presented for a short (500ms) and a long (1000ms) duration to isolate the standard stimulus and comparison stimulus. Participants were asked to judge whether the 2nd stimulus (comparison stimulus) lasted longer/shorter than the standard stimulus.

2.2.4 PROCEDURE

Participants were taken to the experimental lab and asked to sit comfortably. The distance of 57 cm was assured between the participant and display screen. Instructions were given to the participants both in a verbal and written format. They were not allowed to move their heads throughout the experiment. For the visual discrimination task, we used a standard stimulus with a fixed duration of 500ms and comparison stimulus with seven objective durations ranging from 200 to 800 ms with steps of 100 ms. An inter-stimulus interval (ISI) for two varied durations (500ms and 1000ms) was used to segregate comparison stimulus and standard stimulus. In total, each participant performed 182 trials of visual temporal judgments [7 (Durations: 200 to 800 ms) x 2 (ISI: 500 and 1000 ms) x 13 (Repetitions)] (see figure 1)

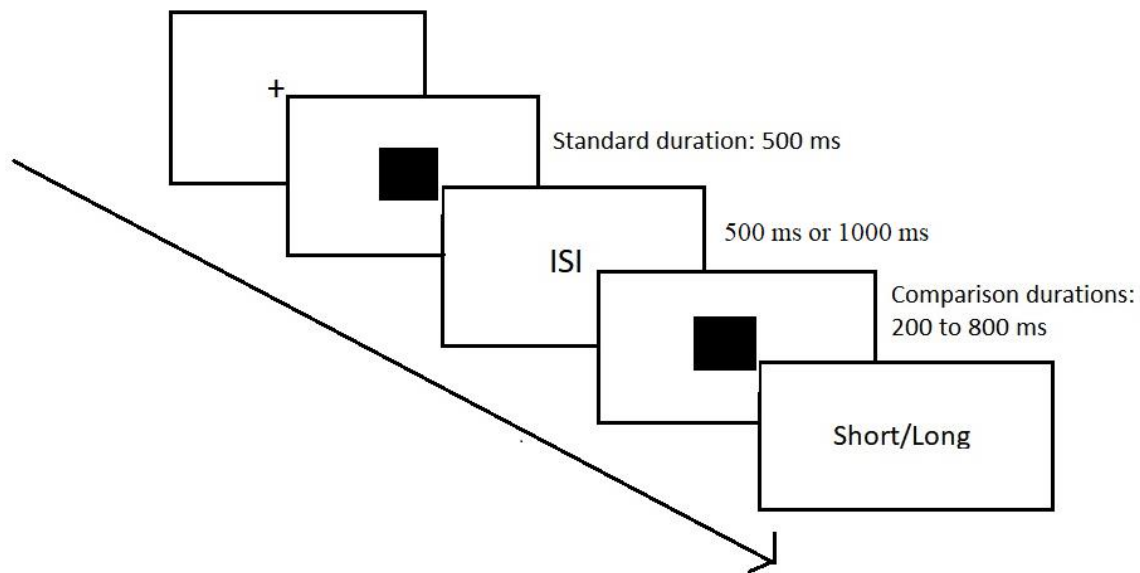


Figure 1: Illustrates the Visual Temporal Discrimination Task. Each trial starts with the presentation of the fixation cross at the center of the screen followed by a black square as the standard stimulus with a fixed duration of 500ms and a comparison stimulus presented with 7 objective durations ranging from 200 to 800ms with the step of 100ms. The standard and comparison stimuli are set apart by a blank screen as the interstimulus interval for two varied durations (500ms and 1000ms) elicits participants to respond indicating whether the comparison stimulus lasts longer or shorter than the standard stimulus.

2.2.5 RESULTS

The participants' data were recorded in an Excel file, categorizing responses as either short or long. JASP Software was used for the statistical analysis of the data. We estimated the *Point of Subjective Equality* (PSE)- the duration at which 50% of the time participants felt the comparison stimulus lasted longer than the standard stimulus and 50% of the time participants felt the comparison stimulus lasted shorter than the standard stimulus. If the PSE value is low, it indicates an overestimation of the duration whereas if the PSE value is high, it indicates an underestimation of the duration. Thus, we fitted a logistic function by using *psignifit-4*, a MATLAB-based toolbox to estimate the point of subjective equality (PSE) for two conditions i.e. short ISI and long ISI. Also, the Difference Limen (DL) was calculated for short ISI and long ISI. DL is a measure of temporal sensitivity in psychophysics. DL measures the smallest difference that can be detected between stimuli; Hence, a smaller DL indicates greater sensitivity or better temporal discrimination, and a larger DL indicates lesser sensitivity or poor temporal discrimination.

Table 1 shows Descriptive statistics for PSE across short ISI and long ISI

	N	Mean	SD	SE	Coefficient of variation
PSE_Short	35	0.512	0.064	0.011	0.125
PSE_Long	35	0.450	0.060	0.010	0.132

The above table shows descriptive statistics for PSE across two different conditions i.e. for short ISI and long ISI. From this table, it can be seen that the PSE value for the condition of short ISI is high and the PSE value for the condition of long ISI is low which suggests that there is an underestimation of the duration in short ISI condition and overestimation of the duration in long

ISI condition. In other words, it can be said that temporal dilation is observed for long ISI and temporal compression is seen for short ISI.

Table 2 shows Paired sample t-test for PSE for short ISI and long ISI

Measure 1	Measure 2	t	df	p	Mean Difference	SE Difference	Cohen's d	SE Cohen's d
PSE_Short	PSE_Long	5.207	34	<.001	0.062	0.012	0.880	0.226

We wanted to investigate whether the perceived duration judgment was altered or not as a function of varying ISI. Thus, the estimated PSE from two different conditions- Short ISI and Long ISI were subjected to paired sample t-tests. The paired sample t-test yielded a statistically significant difference in PSE between short ISI and long ISI [$t(34) = 5.207, p < .001, \text{Cohen's } d = 0.880$] indicating that the temporal perception was modulated by the varied ISIs.

Bar Plots

p1_50(Short) - p2_50(Long)

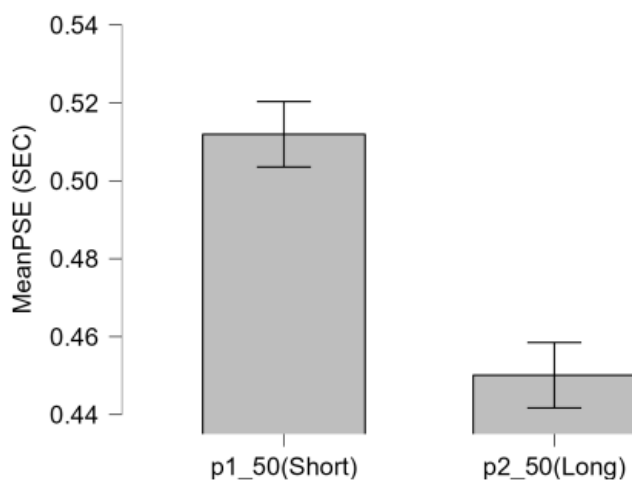


Figure 2: Shows the bar plot for PSE across short ISI and long ISI. PSE is the point at which 50% of the participants perceived the duration to be long and 50% of the participants perceived the duration to be short. A lower PSE indicates an overestimation of the duration (temporal dilation) and a higher PSE indicates an underestimation of the duration (temporal compression). From this,

it can be interpreted that short ISI leads to underestimation of the duration which means participants perceived the duration to be short for Short ISI and long ISI leads to overestimation of the duration which suggests participants perceived the duration to be long.

Table 3 shows Descriptive statistics of DL for short ISI and long ISI

	N	Mean	SD	SE	Coefficient of variation
DL_Short	35	0.112	0.040	0.007	0.357
DL_Long	35	0.095	0.038	0.006	0.396

The above table shows descriptive statistics of DL for two different conditions- Short ISI and long ISI. DL is a measure of temporal sensitivity and from this table, it can be inferred that for short ISI, the DL value is large and for long ISI, the DL value is small. This suggests that there is a higher temporal sensitivity or better temporal discrimination in long ISI condition as compared to short ISI condition which indicates lesser temporal sensitivity or poor discrimination.

Table 4 shows Paired sample t-test for DL for short ISI and long ISI

Measure 1	Measure 2	t	df	p	Cohen's d	SE Cohen's d
DL_Short	DL_Long	2.785	34	0.009	0.471	0.170

To examine whether the variation in ISI can lead to alteration in temporal sensitivity, we calculated the DL for two different conditions- Short ISI and Long ISI and subjected these data to paired sample t-tests. The paired sample t-test yielded a statistically significant difference in DL for short ISI and long ISI [$t(34) = 2.785, p = 0.009, \text{Cohen's } d = 0.471$] suggesting that the variation in ISIs modulated temporal sensitivity.

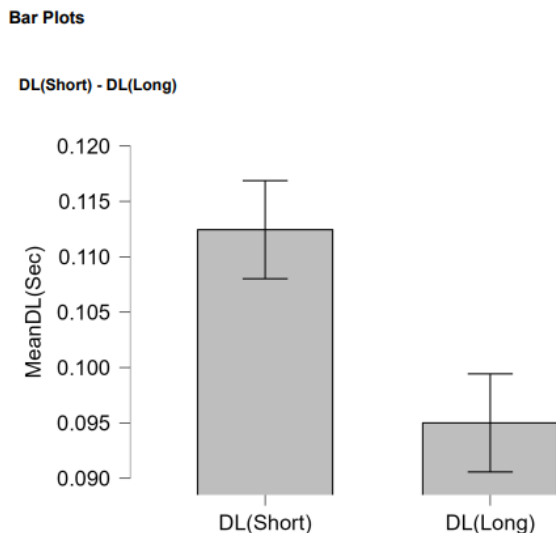


Figure 3: Shows the bar plot for DL across short ISI and long ISI. Difference Limen (DL) is a measure of temporal sensitivity. Smaller DL indicates better temporal discrimination and larger DL indicates poor temporal discrimination. From this, it can be inferred that for short ISI, DL is large which means lesser temporal sensitivity or poor discrimination and for long ISI, value of DL is small which suggests greater sensitivity or better temporal discrimination as compared to short ISI.

Table 5 shows one sample t-test for PSE across short and long PSE

	t	df	p	Mean difference	Cohen's d	SE Cohen's d
PSE_Short	1.106	34	0.276	0.012	0.187	0.171
PSE_Long	-4.958	34	<.001	-0.050	-0.838	0.196

We also conducted one sample t-test on PSE for short ISI and long ISI to check if there is an absolute underestimation or overestimation of the duration as a function of varied ISI. The one sample t-test led us to evaluate whether shorter ISI and longer ISI lies closer to the geometric mean or not. So, from this table, it can be seen that in long ISI condition, there is an overestimation of the time [$t(34) = -4.958, p < .001, \text{Cohen's } d = -0.838$] but no such differences observed in short ISI condition.

EXPERIMENT 2: AUDITORY TEMPORAL DISCRIMINATION TASK

2.3 MATERIALS AND METHODS

2.3.1 PARTICIPANTS

A total of 28 participants were recruited from Thapar Institute of Engineering and Technology, Patiala, Punjab, India in the age range of 18-30 years. The experimental procedures and methodologies adhered to guidelines and regulations and this study got approval from the Institute Review Board (IRB) at Thapar Institute of Engineering and Technology, Patiala, Punjab, India. Informed consent was obtained from all the participants before the conduction of the experiment. No participant reported any history of auditory impairments or problems.

2.3.2 APPARATUS

The presentation and control of stimuli were administered using *OpenSesame* stimulus presentation software (Mathôt et al., 2012). The stimuli were displayed on a 15.3-inch MacBook Air M2 (2880 x 1864) operating at a frame rate of 60 Hz.

2.3.3 PROCEDURE

For the auditory temporal discrimination tasks, the experimental procedures are similar to visual temporal discrimination task, differing only in terms of the stimuli used. Specifically, a sound tone was used as a stimulus for this task which was constructed from a sine wave and had a duration of 1,000 ms with a frequency of 440 Hz. The sound tone was delivered binaurally through *Sennheiser* headphones, with the sound volume being individually adjusted for each participant. In total, each participant performed 168 trials of auditory temporal judgments [7 (Durations: 200 to 800 ms) x 2 (ISI: 500 & 1000 ms) x 12 (Repetitions)]. (see figure 4)

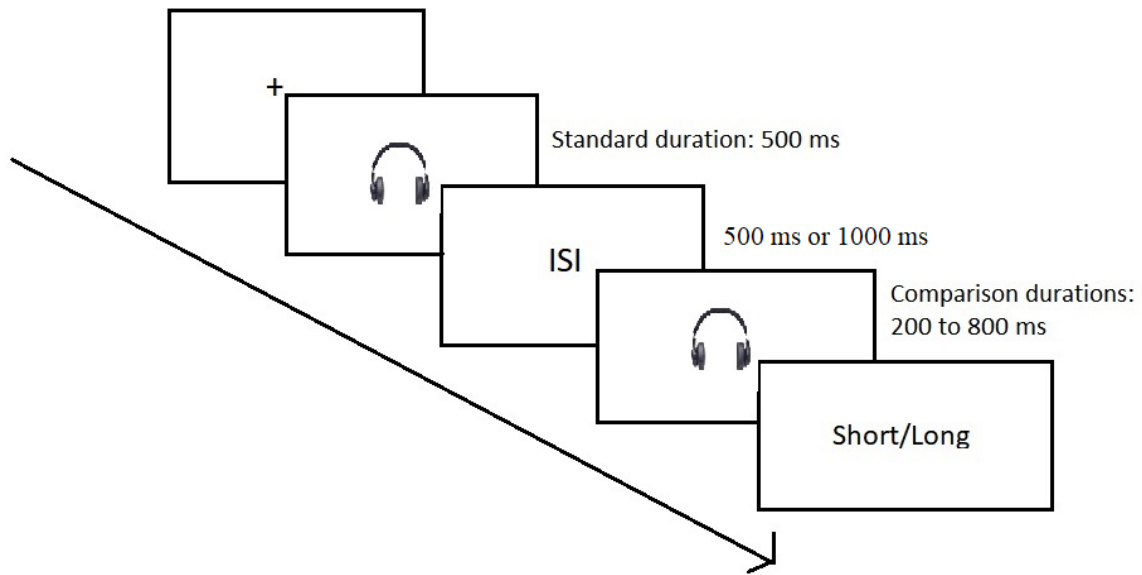


Figure 4: Illustrates the Auditory Temporal Discrimination Task. Each trial starts with the presentation of the fixation cross at the center of the screen followed by a sound tone presented via headphones as the standard stimulus with a fixed duration of 500 ms and a comparison stimulus with 7 objective durations ranging from 200 to 800 ms. The standard and comparison stimulus are set apart by a blank screen as the interstimulus interval (ISI) for two varied durations (500 ms & 1000 ms) eliciting participants to respond indicating whether the comparison stimulus lasts longer or shorter than standard stimulus.

2.3.4 RESULTS

The participants' data were recorded in excel file in terms of short responses and long responses. JASP Software was used for the statistical analysis of the data. We estimated the *Point of Subjective Equality* (PSE)- the duration at which 50% of the time participants felt comparison stimulus lasted longer than standard stimulus and 50% of the time participants felt comparison stimulus lasted shorter than standard stimulus. If PSE value is low, it indicates an over-estimation of the duration whereas if PSE value is high, it indicates an underestimation of the duration. Thus, we fitted a logistic function by using *psignifit-4*, a MATLAB-based toolbox to estimate the point of subjective equality (PSE) for two conditions i.e. short ISI and long ISI. Also, the Difference Limen (DL) was calculated for short ISI and long ISI. DL is a measure of temporal sensitivity in

psychophysics. DL measures the smallest difference that can be detected between stimuli; Hence, smaller DL indicates greater sensitivity or better temporal discrimination and larger DL indicates lesser sensitivity or poor temporal discrimination.

Table 6 Descriptive statistics for PSE for short ISI and long ISI in auditory modality.

	N	Mean	SD	SE	Coefficient of variation
PSE_Short	28	0.473	0.056	0.011	0.117
PSE_Long	28	0.458	0.060	0.011	0.130

The above table shows descriptive statistics for PSE across two different conditions i.e. for short ISI and long ISI. From this table, it can be seen that the value of PSE for the short ISI is large and the value of PSE for the long ISI condition is small which suggests that there is an underestimation of the duration in the short ISI condition and overestimation of the duration in long ISI condition, consistent to result of the visual experiment.

Table 7 shows Paired sample t-test for PSE for short and long ISI in auditory modality.

Measure 1	Measure 2	t	df	p	Mean Difference	SE Difference	Cohen's d	SE Cohen's d
PSE_Short	PSE_Long	2.555	27	0.016	0.015	0.007	0.426	0.120

We wanted to investigate whether the temporal accuracy (judgment) was changed or not as a function of varying ISI in the auditory domain. Thus, we calculated the PSE from two different conditions- Short ISI and Long ISI and subjected to paired sample t-tests. The t-test yielded a statistically significant difference in PSE between short ISI and long ISI [$t(27) = 2.255$, $p = 0.016$, Cohen's $d = 0.426$] suggesting the modulation in temporal perception as a function of varying ISI.

Bar Plots

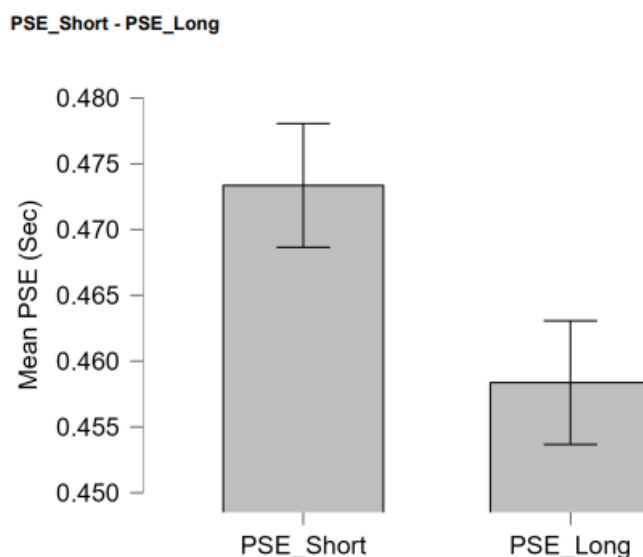


Figure 5 : Shows the bar plot for PSE across short ISI and long ISI in auditory modality. The point of Subjective Equality is near the arithmetic mean of the two extreme durations. Notably, lower PSE value indicates temporal dilation for the duration and a higher PSE indicates temporal compression for the duration. From the above bar plot, it can be interpreted that underestimation of the duration is seen in the condition of Short ISI i.e. participants perceived the duration to be short and overestimation of the duration is observed for long ISI i.e. participants perceived the duration to be long.

Table 8 shows descriptive statistics for DL for short and long ISI in the auditory modality

	N	Mean	SD	SE	Coefficient of variation
DL_Short	28	0.054	0.026	0.005	0.472
DL_Long	28	0.050	0.021	0.004	0.429

The above table shows descriptive statistics of DL for Short and long ISI. From this table, it can be observed that the DL value is large for short ISI and the DL value is small for long ISI with a mean difference of 4 ms.

Table 9 shows paired sample t-test for DL for short and long ISI in auditory modality

Measure 1	Measure 2	Test	Statistic	z	df	p	SE Difference	Effect size
DL_Short	DL_Long	Student	1.478	0.016	27	0.075	0.003	0.279
		Wilcoxon	260.000	1.298		0.101		0.281

To see whether the variation in interstimulus delay in the auditory domain leads to differential temporal sensitivity, the estimated DL for Short and Long ISI and carried out a paired sample t-tests. The test did not yield a statistically significant difference in DL for short and long ISI [$t(27) = 1.298, p = 0.101, \text{Cohen's } d = 0.281$] indicating that the varied ISI did not modulate the temporal sensitivity for the auditory discrimination task.

Bar Plots

DL_Short - DL_Long

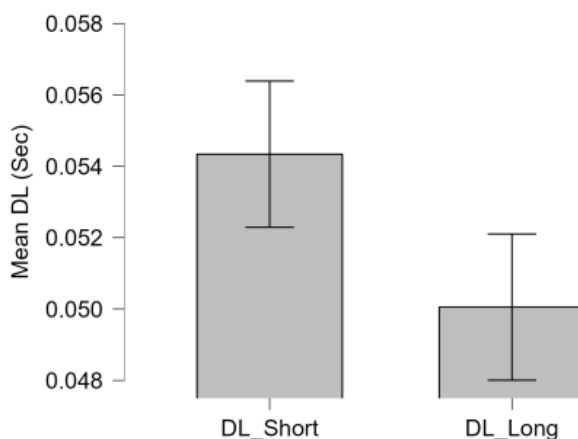


Figure 6: Shows the bar plot for DL across short ISI and long ISI in auditory modality. Difference Limen (DL) is a measure of temporal sensitivity. Remarkably, smaller DL indicates better temporal discrimination and larger DL indicates poor temporal discrimination. From this bar plot, it can be inferred that for short ISI, DL is large which means lesser temporal sensitivity or poor

discrimination and for long ISI, value of DL is small which suggests greater sensitivity or better temporal discrimination as compared to short ISI. But contrastingly, we haven't got any significant difference between the DL for short as well as long ISI (refer table 9).

2.4 DISCUSSION

The aim of the present study is to investigate how variation in ISI can lead to differential time perception in experimental lab settings and compare if varied ISI is affecting one temporal judgment or the other. We hypothesized that there would be a perceived expansion of time for long ISI as compared to short ISI for both visual and auditory tasks. To study this behavior, we adapted a temporal discrimination paradigm and conducted two experiments- Visual Temporal Discrimination task and Auditory temporal discrimination task. In time perception experiments, there are predominant cognitive models to give us an insight about the mechanism behind the results. Two existing models which help us to explain how the human brain processes information and perceives time to be the Internal Clock Model and Attentional Gate Model. According to the Internal Clock Model, pacemaker emit pulses at a given rate and these pulses get stored in the accumulator during the event to be timed (Church, 1984; Treisman et al., 1990). The clock- speed affect is directly proportional to the durations being timed which means if more pulses are accumulated, longer will be the duration judgment. The second model i.e. Attentional Gate Model assumes that only if attention is paid to temporal properties of the event, pulses emitted from pacemaker will be accumulated (Zakay & Block, 1997). Hence, if more attention is paid to an event, it will lead to the overestimation of the duration and if less attention is paid, underestimation of the duration will be observed.

Results of Experiment 1 (Visual discrimination task) as well as Experiment 2 (Auditory discrimination task) showed significant differences in mean PSE for short and long ISI. For short

ISI, PSE was high which signifies underestimation of the duration but for long ISI, PSE is low which signifies overestimation of the duration. Further, to investigate whether short ISI and long ISI affected temporal sensitivity, we also calculated Difference Limen for short ISI and long ISI in both the visual and auditory tasks. For visual task, we observed a significant difference in Difference limen which gives us an idea of low Difference Limen for long ISI and high Difference Limen for short ISI. From this, it can be concluded that there is better discrimination for long ISI and poor discrimination for short ISI in visual condition. But, contrary, we did not observe any DL differences in auditory tasks. This potential difference in the DL result may be due to modality effect. We speculate that temporal sensitivity across the different modality is different and therefore, visual condition we observed the sensitivity differences across different ISI conditions. However, such difference disappeared in auditory task. Further, it can be due to an unequal number of participants in both the tasks for which visual task, we have a greater number of participants as compared to auditory task. Future research should consider having a greater number of participants to validate this finding.

The PSE results for both visual and auditory discrimination tasks can be better explained by the internal clock model. Researchers have found that within this theoretical framework, non-temporal properties of an event also influence the speed of the internal clock (Matthews & Meck, 2016; Wearden et al., 1998). This attempts to explain the nature of underestimation or overestimation of subjective duration in short and long ISI respectively for both visual and auditory discrimination tasks. At the onset of any event, the switch gets closed to allow pulses from the pacemaker to get stored in the accumulator and at the offset of any event, switch gets open and thereby stopping the transfer of pulses into the accumulator. In this case, there is a change in durations and because of that, the internal clock's speed is also getting changed. There is a possibility that change in duration

is creating some sort of rhythm and that particular rhythm may arouse in nature. In other words, constant changes in delay may alter the pace of our internal clock. This means that during events with short ISIs, the pace slows down, resulting in fewer pulses being accumulated in the cognitive counter. Conversely, during events with long ISIs, the pace speeds up, leading to more pulses being accumulated. Therefore, subjective duration tends to be overestimated for long ISIs and underestimated for short ISIs. This highlights the importance of implicit temporal properties of an event which bring about the change in speed of the internal clock. The findings of our study are in line with previous research suggesting that speeding up of the internal clock led to temporal expansion of duration (Matthews & Meck, 2016).

2.5 SUMMARY

The present study investigated how variation in ISI can lead to differential temporal processing in two different modalities such as visual and auditory. Our experimental data suggest that temporal accuracy (judgment) and temporal sensitivity (discrimination) are affected by the variations in Interstimulus Interval (ISI) for visual task but for auditory tasks, variations in Interstimulus Interval (ISI) lead to subsequent changes in only temporal accuracy (judgment) but did not modulate temporal sensitivity (discrimination) itself. From this, it is clear that variations in Interstimulus Interval (ISI) is leading to differential temporal engagement for short ISI and long ISI in two different modalities but it still not clear whether this effect would still persist if we vary the delay between the presentation of stimuli in emotional-context temporal task. This leads to the further examination of the influence of Interstimulus delay under the emotional context using the same paradigm.

CHAPTER 3

INFLUENCE OF DELAY ON TEMPORAL PROCESSING UNDER EMOTIONAL CONTEXT

3.1 INTRODUCTION

Time Perception is a widely studied phenomenon in different fields such as cognition, neuropsychology, psychology etc. to understand human behavior. Many studies in different contexts have been conducted to see how humans experience, process and scale the time. Our awareness, our ability to give meaning to any surrounding event and our individuality is all relative to time perception allowing us to form a link between past, present and future (Lernia et al., 2018). The saying ‘Waiting for entrance results’ and ‘waiting for New Year’s Eve’ exemplifies how the same waiting period is perceived differently. This is how physical time or objective time is converted into psychological time or subjective time depending upon person to person and thus, these are two different constructs that exist in time perception. There are various factors which influence the perceived time by a person such as our mood and emotions. There is a growing body of evidence in which it has been shown that patients suffering from cancer with high anxiety (Wittmann et al., 2006) and patients suffering from mental health issues such as depression (Bschor et al., 2004) tend to overestimate the time. This is because of the worries they are facing in their lives that shifts their attention from meaningful contexts to their psychological issues. Similarly, people who experience more boredom in their lives tend to overestimate the time as compared to people who get less bored (Danckert & Allman 2005). A multitude of research has been done to confirm this assumption that affective states do bring a change in perception of time (James, 1890; Fraisse, 1978; Izard, 2009). Valence and arousal are two distinct concepts which are studied in the context of emotions. Valence is the person’s subjective judgment of affective state

which varies from positive to negative (Lazarus, 1991; Harmon-Jones et al., 2011). On the other hand, arousal is a force that can range subjectively from calmness to excitement or by the sympathetic nervous system's activation (Duffy, 1957, 1962; Gable & Harmon-Jones, 2013). Thus, on reviewing the literature, researchers have posited that positive stimuli are underestimated than negative stimuli (Stetson et al., 2007; Grommet et al., 2011). Alternatively, negative valence stimuli are overestimated than positively valenced stimuli (Angrilli et al., 1997; Droit-Volet et al., 2004; Noulhiane et al., 2007).

Emotions have a very strong impact on time perception. A 2004 temporal bisection study conducted by Droit-volet et al in which they explored the effect of emotions on time perception revealed that angry faces are perceived to occur for longer duration as compared to neutral faces. Thus, if a person sees an angry face, perception of time will be altered. These findings are consistent with existing literature that whenever we encounter a threatening situation or see something unpleasant, there is an increase in arousal which accelerates the pacemaker to emit more pulses within the same physical unit of time or if more attention is paid to the temporal properties of an event, there will be the overestimation of duration, perceiving the duration to be longer (Droit-Volet & Meck, 2007).

Another study by Cocenas-Silva et al., (2013) in which researchers adopted a temporal generalization paradigm to investigate the influence of emotions on long term memory. They specifically tested if representation of standard duration in long term memory was different when it was encoded in emotional condition vs when it was encoded in neutral condition. Also, they investigated whether this representation is resistant or not to interference effects during the period of memory consolidation. The results of the study indicated that emotions do have an impact on memory especially long term because of the more attention-grabbing stimulus in case of emotional

stimulus vs neutral. This suggests that temporal discrimination was better in emotional condition than neutral condition as the time was encoded better and also, memory traces got stronger in case of emotional stimulus.

Thus, many studies have been done to understand the relationship between emotion and timing mechanism but the effect of emotion on other experimental components such as ISI has been unstudied. So, the present study wishes to adopt a temporal discrimination task to examine the impact of ISI on emotional temporal judgment. Thus, we conducted two experiments- one in which standard and comparison stimuli were presented for the same durations with varied ISI and the other in which standard and comparison were presented for different durations with varied ISI. In this, neutral stimulus was presented as a standard stimulus whereas high-arousing emotional images are presented as a comparison stimulus.

EXPERIMENT 1: EMOTION TEMPORAL DISCRIMINATION TASK

3.2 MATERIALS & METHODS

3.2.1 PARTICIPANTS

A total of 22 participants were recruited from Thapar Institute of Engineering and Technology, Patiala, Punjab, India in the age range of 18-30 years. The experimental procedures and methodologies adhered to guidelines and regulations and this study got approval from the Institute Review Board (IRB) at Thapar Institute of Engineering and Technology, Patiala, Punjab, India. Informed consent was obtained from all the participants before the conduction of the experiment. None of the participants reported any visual impairment when asked to participate.

3.2.2 APPARATUS

The presentation and control of stimuli were administered using *OpenSesame* stimulus presentation software (Mathôt et al., 2012). The stimuli were displayed on a 17-inch CRT monitor (1024 × 768 resolution) operating at a frame rate of 100 Hz.

3.2.3 STIMULUS

The experiment began with the fixation cross presented at the center of the screen. In this temporal discrimination task, emotional pictures were used as a stimulus. These were presented against a black background. Participants were asked to press the spacebar to start the experiment and were shown neutral images of both the genders as the standard stimulus with a fixed duration of 500ms followed by comparison stimulus (high arousing i.e. angry images of both the genders) with seven objective durations ranging from 200 to 800ms. A blank screen as Inter Stimulus Interval (ISI) for two varied durations i.e. 500ms and 1000ms was used to isolate standard stimulus and comparison stimulus. Participants were asked to judge whether the 2nd stimulus i.e. comparison stimulus lasted longer/shorter than standard stimulus. If they felt the comparison stimulus lasted longer than the standard stimulus, they had to press 'L' key and if they felt the comparison stimulus lasted shorter than standard stimulus, they had to press 'S' key.

3.2.4 PROCEDURE

Participants were taken to the experimental lab and asked to sit comfortably. The distance of 57 cm was assured between the participant and monitor screen. Instructions were given to the participants both in a verbal and written format. They were not allowed to move their heads throughout the experiment. For the temporal discrimination task in the context of emotions, we used a standard stimulus with a fixed duration of 500 ms and comparison stimulus with seven objective durations ranging from 200 to 800 ms with steps of 100 ms. An inter-stimulus interval

(ISI) for two varied durations (500 ms & 1000 ms) was used to separate comparison stimulus from standard stimulus. In total, each participant performed 196 trials [7 (Durations: 200 to 800 ms) x 2 (ISI : 500 & 1000 ms) x 14 (Repetitions)]. (see figure 7)

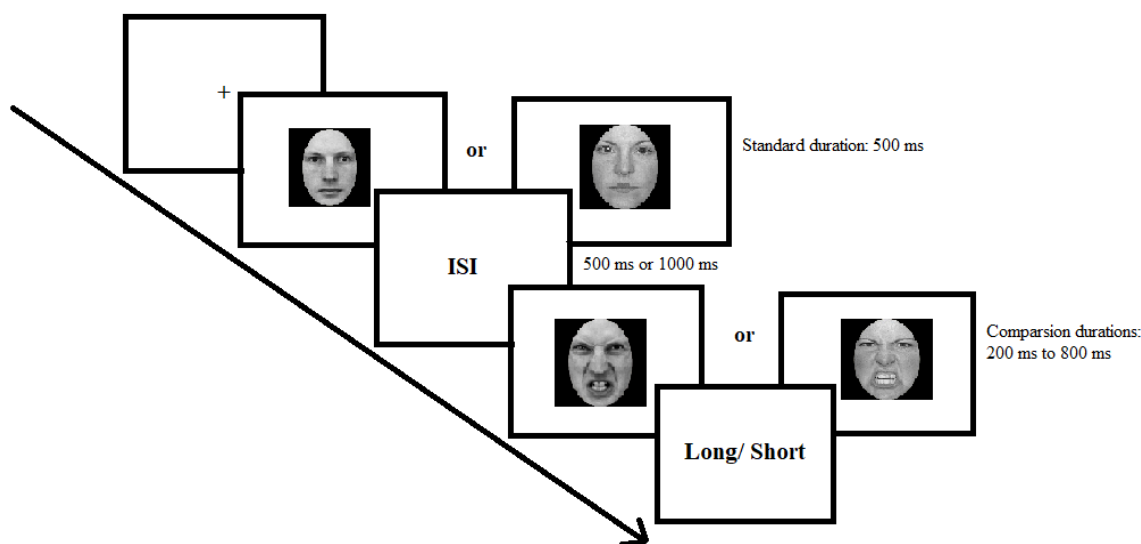


Figure 7: Illustrates the Temporal Discrimination Task in the context of emotions. Each trial starts with the presentation of the fixation cross at the center of the screen followed by neutral emotional stimulus as the standard stimulus with a fixed duration of 500 ms and a comparison stimulus with 7 objective durations ranging from 200 to 800 ms. The standard and comparison stimulus are set apart by a blank screen as the interstimulus interval (ISI) for two varied durations (500 ms & 1000 ms) eliciting participants to respond indicating whether the comparison stimulus lasts longer or shorter than standard stimulus.

3.2.5 RESULTS

The participants' data were recorded in excel file in terms of short responses and long responses. JASP Software was used for the statistical analysis of the data. We estimated the *Point of Subjective Equality* (PSE)- the duration at which 50% of the time participants felt comparison stimulus lasted longer than standard stimulus and 50% of the time participants felt comparison

stimulus lasted shorter than standard stimulus. If PSE value is low, it indicates an over-estimation of the duration whereas if PSE value is high, it indicates an underestimation of the duration. Thus, we fitted a logistic function by using psignifit-4, a MATLAB-based toolbox to estimate the point of subjective equality (PSE) for two conditions i.e short ISI and long ISI. Also, Difference Limen (DL) was calculated for short ISI and long ISI. DL is a measure of temporal sensitivity in psychophysics. While DL measures the smallest difference that can be detected between stimuli. Hence, smaller DL indicates greater sensitivity or better temporal discrimination, and larger large DL indicates lesser sensitivity or poor temporal discrimination.

Table 10 shows Descriptive statistics for PSE across short and long ISI in emotion discrimination task

	N	Mean	SD	SE	Coefficient of variation
PSE_Short	22	0.516	0.053	0.011	0.103
PSE_Long	22	0.459	0.080	0.017	0.173

The above table shows descriptive statistics for PSE across two different conditions- short ISI and long ISI. From this table, it can be deduced that PSE value is high for short ISI and PSE is low for long ISI which suggests that there is an underestimation of the duration in the case of short ISI and overestimation of the duration in long ISI.

Table 11 shows Paired sample t-test for PSE in short and long ISI in emotion discrimination task

Measure 1	Measure 2	t	df	p	Mean Difference	SE Difference	Cohen's d	SE Cohen's d
PSE_Short	PSE_Long	3.584	21	0.002	0.056	0.016	0.764	0.256

We calculated the PSE for two different conditions- Short ISI and Long ISI to see whether the perceived duration judgment was different or not as a function of varying ISI. We subjected these data values to paired sample t-tests; yielding a statistically significant difference in PSE between short ISI and long ISI [$t(21) = 3.584, p = 0.002, \text{Cohen's } d = 0.764$].

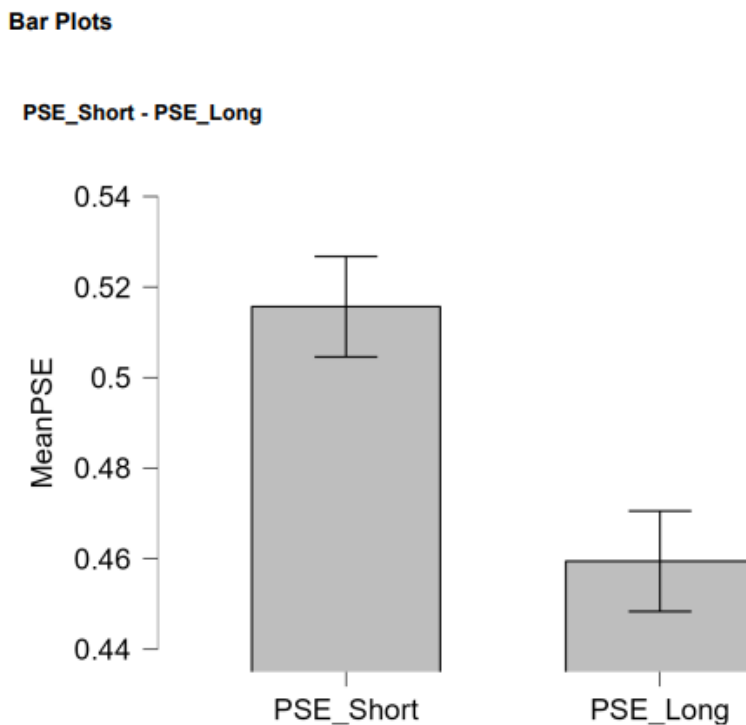


Figure 8: Shows the bar plot for PSE across short ISI and long ISI under emotional context. PSE is the point at which 50 % of the participants perceived the duration longer and 50% of the participants perceived the duration shorter while lower PSE indicating overestimation of the duration and higher PSE indicating underestimation of the duration. From this, it can be interpreted that in the short ISI condition, participants perceived the duration to be short leading to underestimation of the duration and in the long ISI condition, participants perceived the duration to be long leading to overestimation of the duration.

Table 12 shows paired sample t-test for DL for short and long ISI for emotional discrimination task

Measure 1	Measure 2	t	df	p	Mean Difference	SE Difference	Cohen's d	SE Cohen's d
DL_Short	DL_Long	0.686	21	0.250	0.006	0.009	0.146	0.201

To see whether the Interstimulus interval's variation leads to differential temporal sensitivity or not, we estimated the DL for Short ISI and Long ISI and we subjected these data to paired sample t-tests. However, the test did not yield a statistically significant difference in DL for short ISI and long ISI [$t(21) = 0.686, p = 0.250, \text{Cohen's } d = 0.146$].

The results of this experiment suggest that perceived duration was influenced by the varied ISIs in the emotional temporal discrimination task. However, no significant differences in temporal sensitivity were found between the two ISI conditions. Previous experiments focused on the influence of ISI on temporal processing while keeping the standard duration constant and varying the probe stimulus. It remains unclear whether ISI alone affects temporal processing or if variations in both ISI and probe durations jointly influence perceived duration. To address this, we conducted a second experiment where we varied the ISI while keeping the duration the same for both the standard and comparison stimuli.

EXPERIMENT 2: EMOTION TEMPORAL DISCRIMINATION TASK

3.3 MATERIALS & METHODS

3.3.1 PARTICIPANTS

A total of 38 participants were recruited from Thapar Institute of Engineering and Technology, Patiala, Punjab, India in the age range of 18-30 years. The experimental procedures and methodologies adhered to guidelines and regulations and this study got approval from the Institute

Review Board (IRB) at Thapar Institute of Engineering and Technology, Patiala, Punjab, India. Informed consent was obtained from all the participants before the conduction of the experiment. None of the participants reported any visual impairment when asked to participate.

3.3.2 APPARATUS

The presentation and control of stimuli were administered using *OpenSesame* stimulus presentation software (Mathôt et al., 2012). The stimuli were displayed on a 17-inch CRT monitor (1024 × 768 resolution) operating at a frame rate of 100 Hz.

3.3.3 STIMULUS

The experiment began with the fixation cross presented at the center of the screen. In this temporal discrimination task, emotional pictures were used as a stimulus presented against a black background. The difference between Experiment 1 and this experiment is that in the former experiment, duration intervals for standard and comparison are different but in Experiment 2, standard and comparison duration intervals were the same. Participants were asked to press the spacebar to start the experiment and were shown neutral images of both the genders as the standard stimulus with the same duration as the comparison stimulus (high arousing i.e angry images of both the genders). A blank screen as Inter Stimulus Interval (ISI) for two varied durations i.e 500 ms & 1000 ms was used to isolate standard stimulus and comparison stimulus. Participants were asked to judge whether the 2nd stimulus i.e comparison stimulus lasted longer/shorter than standard stimulus. If they felt the comparison stimulus lasted longer than the standard stimulus, they had to press 'L' key and if they felt the comparison stimulus lasted shorter than standard stimulus, they had to press 'S' key.

3.3.4 PROCEDURE- Participants were taken to the experimental lab and asked to sit comfortably. The distance of 57 cm was assured between the participant and monitor screen.

Instructions were given to the participants both in a verbal and written format. They were not allowed to move their heads throughout the experiment. For the temporal discrimination task in the context of emotions, we used a standard stimulus with the same durations as a comparison stimulus with seven objective durations ranging from 200 to 800 ms with steps of 100 ms. An inter-stimulus interval (ISI) for two varied durations (500 ms & 1000 ms) was used to segregate comparison stimulus and standard stimulus. In total, each participant performed 196 trials [7 (Durations: 200 to 800 ms) x 2 (ISI : 500 & 1000 ms) x 14 (Repetitions)] (see figure 9)

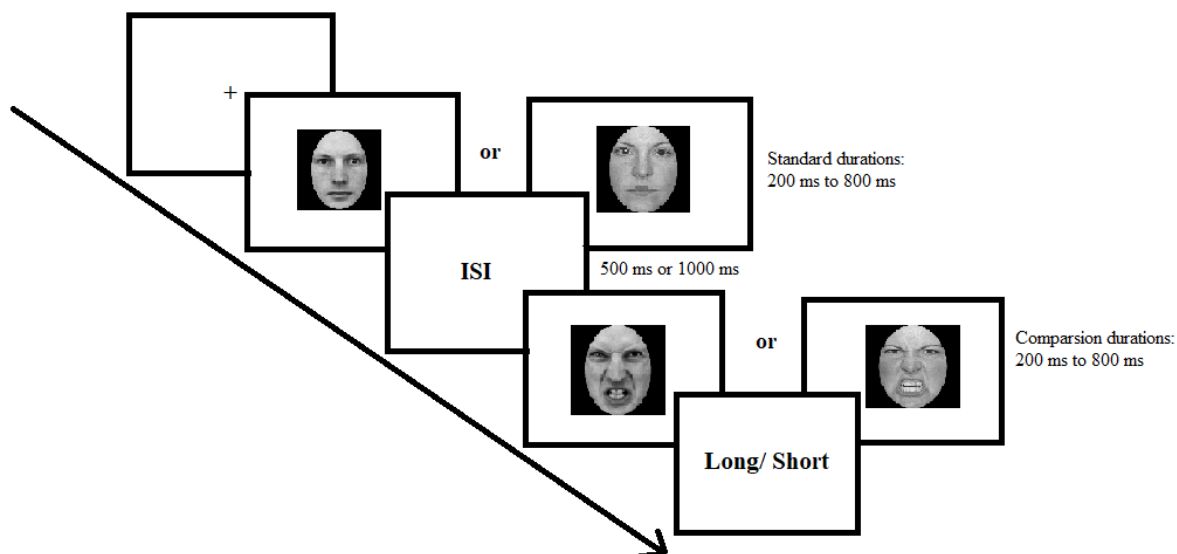


Figure 9 : Shows the Temporal Discrimination Task in the context of emotions. Each trial starts with the presentation of the fixation cross at the center of the screen followed by neutral emotional stimulus as the standard stimulus with the same durations as of comparison stimulus. The standard and comparison stimulus are set apart by a blank screen as the interstimulus interval (ISI) for two varied durations (500 ms & 1000 ms) eliciting participants to respond indicating whether the comparison stimulus lasts longer or shorter than standard stimulus.

3.3.5 RESULTS

The participants' data were recorded in excel file in terms of short responses and long responses. JASP Software was used for the statistical analysis of the data. We analyzed the proportion of long [p(long)] responses in the raw data in the absence of PSE analysis *Proportion Of Long Responses*

[p(long)] is the average proportion of long responses i.e, average of long key presses (“L” key) as compared to short key presses(“S”key)] across different durations.

Table 13 shows Repeated Measures ANOVA

Cases	Sphericity Correction	Sum of Squares	df	Mean Square	F	p	η^2
Delay	None	0.646	1.000	0.646	29.828	<.001	0.021
Residuals	None	0.823	38.000	0.022			
Durations	None	17.235*	6.000*	2.873*	79.673*	<.001	0.565
	Greenhouse-Geisser	17.235	2.241	7.691	79.673	<.001	0.565
Residuals	None	8.220	228.000	0.036			
	Greenhouse-Geisser	8.220	85.155	0.097			
Delay * Durations	None	0.110	6.000	0.018	1.211	0.301	0.004
	Greenhouse-Geisser	0.110	4.915	0.022	1.211	0.306	0.004
Residuals	None	3.463	228.000	0.015			
	Greenhouse-Geisser	3.463	186.755	0.019			

To see the delay as well as duration effect on temporal judgment, we did 2 (Delay: short vs long ISI) x 7 (Durations: 200 to 800 ms) repeated measures ANOVA by analyzing proportion of long responses. The analysis yielded a statistically significant effect of delay with a small effect size ($F(1, 38) = 29.828, p < 0.001, \text{partial } \eta^2 = 0.021$). This indicates differential temporal processing for short delay (short ISI) and long delay (long ISI). Also, a statistically significant effect of durations is also observed with a large effect size ($F(6, 228) = 79.673, p < 0.001, \text{partial } \eta^2 = 0.565$) which suggests that temporal processing for 7 durations (200 ms to 800 ms) were significantly different from each other. However, we did not get any statistical significant

interaction effect for Delay & Durations ($F(6, 228) = 1.211, p = 0.301, \text{partial } \eta^2 = 0.004$).

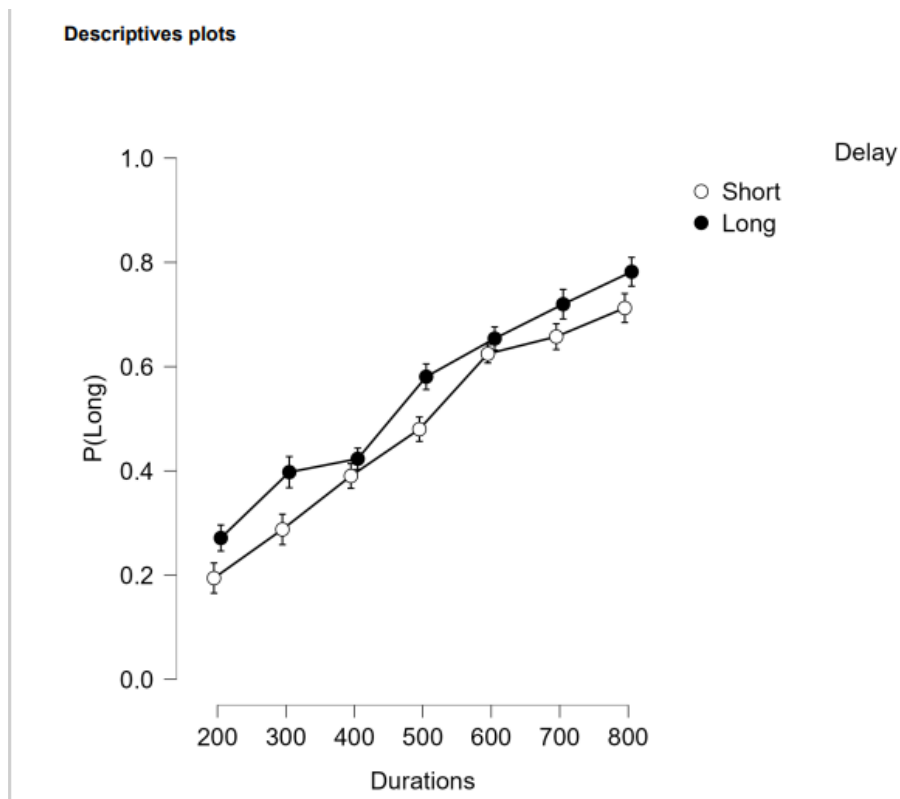


Figure 10: Illustrates the bar plot for proportion of long response [$p(\text{long})$] responses across short ISI and long ISI on durations: The above bar plot shows the delay effect (short ISI and long ISI) on proportion of long responses along Y-axis with 7 durations ranging from 200 ms to 800 ms across X-axis.

3.4 DISCUSSION

In time perception, many researches have been done on emotions which says that both positive and negative emotions alter our perception of time, modulating our attention, arousal, memory and resources that are employed in experiencing the time. The aim of the present study was to employ a task of temporal discrimination in the context of emotions by varying Inter-Stimulus Interval (ISI). Thus, we choose neutral stimulus as standard stimulus and high-arousing stimulus as comparison stimulus with varying ISI for two durations i.e for 500 ms and 1000 ms. We conducted

two experiments in which experiment 1 consists of different durations for both standard and probe stimuli with varying durations of ISI but in experiment 2, standard and probe durations were the same with just varying durations of ISI. In the former, 500 ms was fixed for standard stimulus and comparison stimulus was presented for 7 objective durations ranging from 200 ms to 800 ms but in the latter, standard and comparison stimuli were presented for same durations that if standard stimulus will occur for 200 ms, comparison stimulus will also occur for 200 ms. Both these experiments had these variations in Interstimulus Interval (ISI) for two durations (Short ISI & long ISI). From Study 1, we got a significant difference in short ISI and long ISI by the paired t-test and from barplot, underestimation of the duration can be seen for short ISI condition. and overestimation of the duration can be seen for long ISI conditions. These results can be explained by the cognitive models which attempt to reason for temporal processing judgments and that one model could be Attentional model (e.g., Hicks et al., 1977; Thomas & Weaver, 1975; Zakay, 1989) which presuppose to have the cognitive counter requiring mental resources allocated to the event. The working of this cognitive counter is related to the temporal information processed in a given amount of time. Thus, estimation of time duration depends on the output of what is stored in the cognitive counter (Zakay & Block, 1997). Kahneman (1973) says, ‘ because of limited capacity, when the load is less to process the non-temporal information, attention can be freely allocated to the temporal properties of the event exhibiting a negative relationship between load of non-temporal information processed and magnitude of estimated duration. Thus, according to the attentional model, if the event is empty, there will be higher duration estimation as compared to when the event is filled where the duration estimate would be less (Zakay & Block, 1997). In the context of Experiment 1 , we can say that for short ISI, underestimation could be due to high load to process non- temporal information as the event is filled whereas for long ISI, overestimation

could be due to less load of non- temporal properties and the event is empty, therefore participants perceive the duration to be longer.

This can also be understood by the Attentional Gate Model given by Zakay and Block in 1995 which says that the mechanism of the gate will be determined by attention allocated to time. If more attentional resources are employed to the time, the gate opens early and closes late; thereby the gate is opening for a wider period. As a result, more pulses will be emitted from the pacemaker and get accumulated in the cognitive counter but if attention is allocated towards non- temporal properties, the gate gets closed and no pulses from the pacemaker can pass through. So, in experiment 1, we have used high-arousing emotion for comparison stimulus, and we can assume for long ISI, there is enough time to pay attention to temporal properties, that is why over estimation is to be observed but in the short ISI condition, there is less time to pay attention to temporal properties. Also, there might be possibility that participants are paying attention to non- temporal properties in case of short ISI and there is underestimation to be observed. In sum, if we attend to time, the activity of the gate will automatically be increased. So, it is the latency of gate which will be the deciding factor that there will be underestimation or overestimation of the duration. For experiment 2, we computed the average proportion of *long responses* [p(long)] across seven durations (200 ms to 800 ms) for short delay and large delay. Further, it was explored by using repeated measures ANOVA. The ANOVA analysis yielded a statistically significant main effect of delay with a small effect size and a statistically significant main effect of durations with a large effect size. This indicates differential temporal processing for short ISI and long ISI for the main effect of delay and for the main effect of directions, we get to know that temporal processing for 7 durations were significantly different from each other. However, we did not get any statistical significant interaction effect for Delay & Durations. These results give us an insight about how

both independent variables i.e delay as well as durations have an effect on proportion of long responses. For the main effect of delay, we can infer that independent of the durations, participants had differential temporal processing for short delay and large delay and for the main effect of durations, we can infer that independent of delay, participants perceived the time to be different at each objective duration. Thus, 2 (Delay: short and large) x 7 (Durations: 200 ms to 800 ms) repeated measures ANOVA reveals that $p(\text{long})$ responses systematically increased with increased delay. As the delay increases, the tendency to press the 'L' key increases. Similarly, the $p(\text{long})$ responses systematically increased with increased durations which means as the duration goes from 200 to 800 ms, it elicited more longer responses. This insignificant interaction effect suggests that $p(\text{long})$ responses for the delay were not different across durations. In simple words, it can be said that large delay (long ISI), did not elicit longer responses as compared to short delay (short ISI) on the given durations.

3.5 SUMMARY

The present study wished to examine the impact of varying Interstimulus Interval (ISI) in the temporal discrimination task of high-arousing emotions. Our data from Experiment 1 suggest that temporal accuracy (judgment) gets affected by the short and long ISI but temporal discrimination was not modulated by variations in ISI. However, for Experiment 2, the main effect of delay as well as durations came out to be significant with insignificant interaction between both. These results suggest that such effects can occur from the allocation of attentional resources to temporal properties and non-temporal properties.

CHAPTER 4

GENERAL DISCUSSION & CONCLUSION

The experience of time is a very subjective thing and throughout evolution, there exists a challenge of how to explain the timing mechanism. The most challenging evaluation of ‘Subjective time’ was given by Augustinus (397/398 A.D) in the book of his ‘Confessions.’ His ideas about the subjective time were very fascinating as he linked the time to the event’s perception like how events are perceived by people. This idea was further developed by Gibson in 1975 that time is not perceivable rather events are perceived (Poppel,1978). Hence, time is a unique element, but when it comes to representation of the time, it is often linked with cognitive and perceptual-based resources (Matthews & Meck, 2016). So, in this study, we wanted to investigate the influence of Interstimulus delay by varying it and we tested this using a temporal discrimination paradigm. Thus, we conducted the experiments in different modalities i.e. in Visual and Auditory domains and also study was conducted under emotional contexts.

Since, we have attributed the results to the prominent and existing models of time perception and it can be implied that independent of modality (visual and auditory), we have got significant differences in *point of subjective equality* (PSE) but the significant effect of *Difference Limen* (DL) is only observed for visual discrimination task; not for auditory task. Although, we say that modulating interstimulus delay arouses some sort of arousal in us but if this holds true, then this arousal factor should also be induced in other experimental settings when we are testing this in visual tasks using high- arousing emotions and auditory tasks. So, it would be adequate if we exclude this possibility altogether as the mechanism for these differential effects is not clearly captured by the *Internal Clock Model* and *Attentional Gate Model*. Hence, the current study takes

a different approach by not fully accepting these two theories because they somehow fail to explain the behavior that why in auditory, visual and emotional discrimination tasks, long ISI is leading to overestimation of the duration and short ISI leads to underestimation of duration.

Now, at this stage, the concern that comes to our mind is the potential significance of the study's findings. These findings could be better explained by the alternative mechanism that the brain may not judging the durations in such a way. We speculate that the brain is not encoding time in a sequence but rather capturing a single whole event at one time. For example, if we read a novel, instead of remembering each and every word or character in the story, we capture the core essence or have a main idea of the whole story retrospectively. It is possible that the human brain is structured to view the event in a holistic manner. Thus, we can say the brain integrates the whole event as one entity, so technically what the brain is doing is correct that it is sampling the whole event from standard stimulus till comparison stimulus including the duration of Inter-stimulus interval (ISI), rather than segmenting in different events. In our study, for example, when standard duration is fixed for 500 ms and let's assume to have a short ISI of 500 ms and comparison duration is for 200 ms. Now, if we add these durations, we will in total have 1200 ms. In the 2nd case, standard duration for 500 ms followed by 1000 ms of ISI and comparison duration is for 200 ms again, if we add these durations, that would equal 1700 ms with a difference of 500 ms in both mentioned cases. So, this suggests that the human brain is actually learning to acquire a stamp of these two different time durations. In other words, in case of short ISI i.e for 500 ms, if we add this time to a full trial from fixation to keypress, we will perceive the time to be shorter as the brain is generating more short responses because the entire event is occurring for a shorter duration. But in long ISI (1000 ms), if we add 1000 ms time to a single trial, the brain will automatically sample more longer responses and in result, probability of pressing 'L' key would be high and we will be

overestimating the duration. Specifically, the brain is not encoding the whole event in segments, rather the brain takes the whole trial from fixation to keypress as one entire event and makes the subsequent duration judgment which leads to underestimating the duration whenever an event trial is presented with short ISI and overestimating the duration whenever event trial is presented with long ISI.

The 3rd explanation could be how the participants perceive the waiting time. If the waiting time appears to be longer i.e. if the participants feel that passage of time is passing slowly, there will be an overestimation of the duration compared to less waiting time (Pfeifer & Wittmann, 2020). In the context of this study, we can assume that for short ISI, the period of waiting time is shorter, so the participants perceive the duration to be short and hence, they are underestimating the time duration whereas in long ISI, the brain is taking it as a longer wait and hence, the participants tend to overestimate the duration.

Another interesting aspect could be that underestimation and overestimation of the duration of the same physical time can be related to different experiences of boredom. So, if a person feels the event is taking longer as usual, he/she will experience more boredom at that time (Danckert & Allman 2005). Therefore, in case of short ISI, brain perceives the whole event to be short and the person experiences less boredom at that time leading to the underestimating of duration but in case of long ISI, brain perceives the whole event to be of longer duration and the person experiences more monotony and hence, overestimate the duration.

The limitation of my study would be that sample size was not equal in all the experiments. In the visual temporal discrimination task, the *difference limen (DL)* difference was there but in the remaining experiments, sample size was less so, that could be the reason that we haven't got any

differences in DL. We will require more participants to check whether any DL differences are there or not in auditory and emotional temporal discrimination tasks.

In sum, the study concludes that Interstimulus Interval (ISI) holds an important position in time perception experiments. The variations in interstimulus delay can lead to differential temporal judgments and it holds true for visual and auditory modalities. Also, the results are consistent when this effect has been studied in different contexts such as emotions.

CHAPTER 5

REFERENCES

- Allman, M. J., & Meck, W. H. (2012). Pathophysiological distortions in time perception and timed performance. *Brain: A Journal of Neurology*, 135, 656–677.
- Allman, M. J., Yin, B., & Meck, W. H. (2014). Time in the psychopathological mind. In D. Lloyd & V. Arstila (Eds.), *Subjective time: The philosophy, psychology, and neuroscience of temporality* (pp. 637–654). Cambridge, MA: MIT Press
- Angrilli, A., Cherubini, P., Pavese, A., and Manfredini, S. (1997). The influence of affective factors on time perception. *Percept. Psychophys.* 59, 972–982
- Bae, G., & Kim, D. Y. (2014). The effects of offering menu information on perceived waiting time. *Journal of Hospitality Marketing & Management*, 23(7), 746-767.
- Bartholomew, A. J., Meck, W. H., & Cirulli, E. T. (2015). Analysis of genetic and non-genetic factors influencing timing and time perception. *PLoS ONE*, 10, e0143873.
- Block, R. A., & Zakay, D. (1996). Models of psychological time revisited. *Time and mind*, 33(9), 171-195.
- Block, R. A., Zakay, D., & Hancock, P. A. (1999). Developmental changes in duration judgments: A meta-analytic review. *Developmental Review*, 19, 183–211.
- Block, R. A., Hancock, P. A., & Zakay, D. (2000). Sex differences in duration judgments: A meta-analytic review. *Memory & Cognition*, 28, 1333–1346.
- Buhusi, C. V. & Meck, W. H. 2005 What makes us tick? Functional and neural mechanisms of

- interval timing. *Nat. Rev. Neurosci.* 6, 755–765.
- Buonomano, D. V., Bramen, J., & Khodadadifar, M. (2009). Influence of the interstimulus interval on temporal processing and learning: testing the state-dependent network model. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1525), 1865-1873
- Bschor, T., Ising, M., Bauer, M., Lewitzka, U., Skerstuepit, M., Muller-Oerlinghausen, B. & Baethge, C. 2004 Time experience and time judgment in major depression, mania and healthy subjects. A controlled study of 93 subjects. *Acta Psychiatr. Scand.* 109, 222–229.
- Cai, Z. G., and Wang, R. (2014). Numerical magnitude affects temporal memories but not time encoding. *PLoS One* 9:e83159.
- Callender, C. (2010). Is time an illusion? *Scientific American Mind*, 302, 58–65.
- Chang, A. Y. C., Tzeng, O. J., Hung, D. L., and Wu, D. H. (2011). Big time is not always long: numerical magnitude automatically affects time reproduction. *Psychol. Sci.* 22, 1567–1573.
- Church, R. M. 1984 Properties of the internal clock. In *Timing and time perception*, vol. 423 (eds J. Gibbon & L. Allan), pp. 566–582. New York, NY: New York Academy of Sciences
- Cocenas-Silva, R., Bueno, J. L. O., & Droit-Volet, S. (2013). Emotion and long-term memory for duration: Resistance against interference. *Behavioural Processes*, 97, 6-10.
- Danckert, J. A. & Allman, A. A. A. 2005 Time flies when you're having fun: temporal estimation and the experience of boredom. *Brain Cogn.* 59, 236–245.

- Di Lernia, D., Serino, S., Pezzulo, G., Pedroli, E., Cipresso, P., & Riva, G. (2018). Feel the time. Time perception as a function of interoceptive processing. *Frontiers in human neuroscience, 12*, 74.
- Droit-Volet, S., Brunot, S., and Niedenthal, P. M. (2004). Perception of the duration of emotional events. *Cognit. Emot.* 18, 849–858
- Droit-Volet, S., Brunot, S., & Niedenthal, P. (2004). BRIEF REPORT Perception of the duration of emotional events. *Cognition and emotion, 18*(6), 849-858.
- Droit-Volet, S., Meck, W. H., & Penney, T. B. (2007). Sensory modality and time perception in children and adults. *Behavioural processes, 74*(2), 244-250.
- Droit-Volet, S., & Meck, W. H. (2007). How emotions colour our perception of time. *Trends in cognitive sciences, 11*(12), 504-513.
- Droit-Volet, S. and Rattat, A.C. (2007) A further analysis of temporal bisection behavior in children with and without reference memory: the similarity and the partition task. *Acta Psychol (Amst.)* 125, 240–256
- Droit-Volet, S. (2012). Children and time. *The Psychologist, 25*, 586–589.
- Droit-Volet, S., & Zélanti, P. S. (2013). Development of time sensitivity and information processing speed. *PLoS ONE, 8*, 1–9.
- Duffy, E. (1957). The psychological significance of the concept of “arousal” and activation. *Psychol. Rev.* 64, 265–275.

- Duffy, E. (1962). *Activation and Behavior*. New York, NY: Wiley
- Effron, D. A., Niedenthal, P. M., Gil, S., & Droit-Volet, S. (2006). Embodied temporal perception of emotion. *Emotion*, 6(1), 1.
- Gibson, J. J. (1975). Events are perceivable but time is not. In *The Study of Time II: Proceedings of the Second Conference of the International Society for the Study of Time Lake Yamanaka-Japan* (pp. 295-301). Berlin, Heidelberg: Springer Berlin Heidelberg.
- Grommet, E. K., Droit-Volet, S., Gil, S., Hemmes, N. S., Baker, A. H., and Brown, B. L. (2011). Time estimation of fear cues in human observers. *Behav. Process.* 86, 88–93.
- Grondin, S. (2001). From physical time to the first and second moments of psychological time. *Psychological Bulletin*, 127, 22–44.
- Grondin, S. (2010a). Timing and time perception: A review of recent behavioral and neuroscience findings and theoretical directions. *Attention, Perception & Psychophysics*, 72, 561–582.
- Fraisse, P. (1978). "Time and rhythm perception," in *Handbook of Perception*, Vol. 8, eds E. C. Carterette and M. P. Friedmans (Cambridge, MA: Academic Press), 203–254
- Gable, P. A., and Harmon-Jones, E. (2013). Does arousal per se account for the influence of appetitive stimuli on attentional scope and the late positive potential? *Psychophysiology* 50, 344–350.
- Grondin, S. (2010). Unequal Weber fractions for the categorization of brief temporal intervals. *Attention, Perception & Psychophysics*, 72(5), 1422–1430.

- Hancock, P. A., & Rausch, R. (2010). The effects of sex, age, and interval duration on the perception of time. *Acta Psychologica*, 133, 170–179.
- Harmon-Jones, C., Schmeichel, B. J., Mennitt, E., and Harmon-Jones, E. (2011). The expression of determination: similarities between anger and approach related positive affect. *J. Pers. Soc. Psychol.* 100, 172–181.
- Hicks, R.E. • Miller, G.W. • Gacs, G. and Bicrman, K. (1977). Concurrent processing demands and the experience of time in passing. *American Journal Of Psychology*, 2Q, 413-446.
- Ioan, S., Sandulache, M., Avramescu, S., Ilie, A., Neacsu, A., Zagrean, L., & Moldovan, M. (2007). Red is a distractor for men in competition. *Evolution and Human Behavior*, 28(4), 285-293.
- Izard, C. E. (2009). Emotion theory and research: highlights, unanswered questions, and emerging issues. *Annu. Rev. Psychol.* 60, 1–25.
- James, W. (1890). *The Principles of Psychology*. Mineola, NY: Dover Publications.
- Kahneman, D. (1973). *Attention and effort* (Vol. 1063, pp. 218-226). Englewood Cliffs, NJ: Prentice-Hall.
- Karmarkar, U. R., & Buonomano, D. V. (2007). Timing in the absence of clocks: encoding time in neural network states. *Neuron*, 53(3), 427-438.
- Lazarus, R. S. (1991). *Emotion and Adaptation*. New York, NY: Oxford University Press.
- LeDoux, J. E. (1998). *The emotional brain: The mysterious underpinnings of emotional life*. Simon and Schuster.

- LeDoux, J. (2012). Rethinking the emotional brain. *Neuron*, 73(4), 653-676.
- Le Poidevin, R. (2000). The experience and perception of time.
- Macar, F., & Vidal, F. (2009). Timing processes: An outline of behavioural and neural indices not systematically considered in timing models. *Canadian Journal of Experimental Psychology*, 63, 227–239
- Mella, N., Conty, L., & Pouthas, V. (2011). The role of physiological arousal in time perception: Psychophysiological evidence from an emotion regulation paradigm. *Brain and Cognition*, 75, 182–187.
- Mather, M. (2007). Emotional arousal and memory binding: An object-based framework. *Perspectives on Psychological Science*, 2(1), 33-52.
- Mathôt, S., Schreij, D., and Theeuwes, J. (2012). OpenSesame: An open-source, graphical experiment builder for the social sciences. *Behav. Res. Methods* 44, 314–324.
- Matthews, W. J., & Meck, W. H. (2014). Time perception: the bad news and the good. *Wiley Interdisciplinary Reviews: Cognitive Science*, 5(4), 429-446.
- McCormack, T. (2015). The development of temporal cognition. In R. M. Lerner (Ed.), *Handbook of child psychology and developmental science* (7th ed., Vol. 2, pp. 624–670). New York, NY: Wiley.
- Mella, N., Conty, L., & Pouthas, V. (2011). The role of physiological arousal in time perception: Psychophysiological evidence from an emotion regulation paradigm. *Brain and Cognition*, 75, 182–187.

- Mittal, J., Juneja, K. K., Saumya, S., & Shukla, A. (2024). A matter of time: how musical training affects time perception. *Frontiers in Neuroscience*, *18*, 1364504.
- Noulhiane, M., Mella, N., Samson, S., Ragot, R., and Pouthas, V. (2007). How emotional auditory stimuli modulate time perception. *Emotion* *7*, 697–704.
- Oliveri, M., Vicario, C. M., Salerno, S., Koch, G., Turriziani, P., Mangano, R., et al. (2008). Perceiving numbers alters time perception. *Neurosci. Lett.* *438*, 308–311
- Parsons, L. M. (2001). Exploring the functional neuroanatomy of music performance, perception, and comprehension. *Ann. N. Y. Acad. Sci.* *930*, 211–231.
- Pöppel, E. 1997 A hierarchical model of temporal perception. *Trends Cogn. Sci.* *1*, 56–61.
- Pfeifer, E., & Wittmann, M. (2020). Waiting, thinking, and feeling: variations in the perception of time during silence. *Frontiers in Psychology*, *11*, 522217.
- Rammsayer, T., & Altenmüller, E. (2006). Temporal information processing in musicians and nonmusicians. *Music Perception*, *24*(1), 37-48.
- Pöppel, E. (1978). Time perception. *Handbook of sensory physiology*, *8*, 713-729.
- Sharot, T., & Phelps, E. A. (2004). How arousal modulates memory: Disentangling the effects of attention and retention. *Cognitive, Affective, & Behavioral Neuroscience*, *4*(3), 294-306.
- Shibasaki, M., & Masataka, N. (2014). The color red distorts time perception for men, but not for women. *Scientific reports*, *4*(1), 5899.
- Shukla, A., and Bapi, R. S. (2021). Attention mediates the influence of numerical magnitude on temporal processing. *Sci. Rep.* *11*:11030.

- Shukla, A., and Bapi, R. S. (2022). Number-time interaction: Search for a common magnitude system in a cross-modal setting. *Front. Behav. Neurosci.* 16:891311.
- Skagerlund, K., Karlsson, T., and Träff, U. (2016). Magnitude processing in the brain: an fMRI study of time, space and numerosity as a shared cortical system. *Front. Hum. Neurosci.* 10:500.
- Smith, S. D., McIver, T. A., Di Nella, M. S., & Crease, M. L. (2011). The effects of valence and arousal on the emotional modulation of time perception: evidence for multiple stages of processing. *Emotion*, 11(6), 1305.
- Stetson, C., Fiesta, M. P., and Eagleman, D. M. (2007). Does time really slow down during a frightening event? *PLoS One* 2:e1295.
- Sturt, M. (1925). *The psychology of time.* (1st ed.). Routledge
- Thomas, E.A.C., & Cantor, N.E. (1975). On the duality of simultaneous time and size perception. *Perception & Psychophysics*, 18,44-48.
- Thomas. E.A.C. and Weaver. W.B. (1975). Cognitive processing and time perception. *Perception and Psychophysics*, 17, 363-367
- Tinklenberg, J. R., Roth, W. T. & Kopell, B. S. 1976 Marijuana and ethanol: differential effects on time perception, heart rate, and subjective response. *Psychopharmacology* 49, 275–279.
- Tipples, J. (2011). When time stands still: Fear-specific modulation of temporal bias due to threat. *Emotion*, 11, 74–80.

- Treisman, M. (1963). Temporal discrimination and the indifference interval: Implications for a model of the " internal clock". *Psychological Monographs: General and Applied*, 77(13), 1.
- Treisman, M., Faulkner, A., Naish, P. L. N. & Brogan, D. 1990. A The internal clock: evidence for a temporal oscillator underlying time perception with some estimates of its characteristic frequency. *Perception* 19, 705–743.
- Vatakis, A., & Allman, M. J. (Eds.). (2015). *Time distortions in mind: Temporal processing in clinical populations*. Boston, MA: Brill Academic Publishers.
- Vuilleumier, P., Armony, J. L., Driver, J., & Dolan, R. J. (2003). Distinct spatial frequency sensitivities for processing faces and emotional expressions. *Nature neuroscience*, 6(6), 624-631.
- Wearden, J. H., Edwards, H., Fakhri, M., & Percival, A. (1998). Why “sounds are judged longer than lights”: Application of a model of the internal clock in humans. *Quarterly Journal of Experimental Psychology*, 51, 97–120.
- Wearden , J. H., & Penton-Voak, I. S. (1995). Feeling the heat: Body temperature and the rate of subjective time, revisited. *Quarterly Journal of Experimental Psychology*, 48, 129–141
- Wittmann, M. 1999 Time perception and temporal processing levels of the brain. *Chronobiol. Int.* 16, 17–32.
- Wittmann, M., Vollmer, T., Schweiger, C. & Hiddemann, W. 2006 The relation between the experience of time and psychological distress in patients with hematological

malignancies. *Palliat. Support. Care* 4, 357–363.

Zakay, D. (1989). Subjective time and attentional resource allocation: an integrated model of time estimation. In: I. Levin and D. Zakay (Eds.) *Time and Human Cognition . A Life Span Perspective*. Amsterdam: North Holland, 365-398.

Zakay, D., & Block, R. E. (1995). An attentional -gate model of prospective time estimation. In M. Richelle, V. D. Keyser, G. D. Ydeualle, & A. Vandierendonck (Eds.), *Time and the dynamic control of behavior*. Liege: University of Liege Press

Zakay, D. & Block, R. A. (1997) Temporal cognition. *Curr. Dir. Psychol. Sci.* 6, 12–16

APPENDICES

APPENDIX A: CONSENT FORM FOR STUDY-1

The purpose of this experiment is to understand how people perceive time. This research is a part of my dissertation thesis under the supervision of Dr. Anuj Kumar Shukla This is a discrimination/comparison task. You will be shown two stimuli one after the other. All you need to do is compare 2nd stimulus with 1st stimulus in terms of duration. You will be allotted two keys where you will be making the judgment whether the 2nd stimulus lasted longer/shorter than the 1st stimulus.

- Participation in the experiment is voluntary
- Data will be kept confidential
- Subjects' identity will be protected
- The experiment will last for 10-15 minutes.
- If you have any questions, please clarify them before proceeding and if you have any doubts after the experiment, you can contact us in future at our email address mentioned below
- jmittal_ma22@thapar.edu
- anuj.shukla@thapar.edu

Signed.....

(Researcher)

Subject Demographic details

Name.....Age.....

Gender.....Education.....

Contact Number.....

I,....., give my consent for the participation in this.....experiment conducted by.....

I understand that:

- My data will be used for the research
- My participation is voluntary.
- My information will be kept confidential.

I have read the information above and I give my consent for my participation in this study.

Signed,.....

Date.....

APPENDICES

APPENDIX B: CONSENT FORM FOR STUDY-2

The purpose of this experiment is to understand how people perceive time. This research is a part of my dissertation thesis under the supervision of Dr. Anuj Kumar Shukla This is a discrimination/comparison task. You will be shown two stimuli one after the other. All you need to do is compare 2nd stimulus with 1st stimulus in terms of duration. You will be allotted two keys where you will be making the judgment whether the 2nd stimulus lasted longer/shorter than the 1st stimulus.

- Participation in the experiment is voluntary
 - Data will be kept confidential
 - Subjects' identity will be protected
 - The experiment will last for 10-15 minutes.
 - If you have any questions, please clarify them before proceeding and if you have any doubts after the experiment, you can contact us in future at our email address mentioned below
- jmittal_ma22@thapar.edu
- anuj.shukla@thapar.edu

Signed.....

(Researcher)

Subject Demographic details

Name.....Age.....

Gender.....Education.....

Contact Number.....

I,....., give my consent for the participation in this.....experiment conducted by.....

I understand that:

- My data will be used for the research
- My participation is voluntary.
- My information will be kept confidential.

I have read the information above and I give my consent for my participation in this study.

Signed,.....

Date.....