An Exploration of the Factors That Influence Attention in Task Performance

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CERTIFICATE

This is to certify that the thesis titled **An Exploration of the Factors that Influence Attention in Task Performance** submitted by **Krithika Nambiar** ID No **2019PHXF0436H** for award of Ph.D. of the Institute embodies original work done by him/her under my supervision.

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Abstract

We perceive the world around us through our sensory perceptions, such as vision, hearing, smell, taste, and touch, which allow us to detect perceptual stimuli. These sensory inputs provide information about our environment, and our brain uses attention to highlight some aspects of the stimuli before processing this information to form a comprehensive understanding of the objects in our surroundings. This process enables us to learn about the world and interact with it effectively, which we refer to as performing a task. Perceptual Load Theory is the model that attempts to explain the interaction between attention, target, and distractor in task performance. The findings of the theory have significantly improved our understanding of the functions, challenges, and failures of attention in performing different types of tasks. However, the findings are based mostly on visual modality experiments, and have failed to take some parameters of task type, nature of task, and individual's expertise into consideration. In this thesis, I raise important research questions based on the interaction of attention with these parameters, while reporting on the studies that attempt to find answers to these questions.

Chapters 1 and 2 present a conceptual mind map focusing on load theories and parameters relevant to understanding selective attention in behavioural studies. Our sensory organs continuously transmit information about various stimuli to the brain. However, not all of this information is pertinent or useful for the task at hand. The brain's resources are limited, and processing all available information is impractical. Therefore, the brain must prioritise and allocate its resources to concentrate on the pertinent aspects of the stimuli. This cognitive process, selective attention, allows us not only to filter out irrelevant aspects of a stimulus but also to block out entirely irrelevant stimuli, referred to as distractors. Despite recognising selective attention as a mechanism that enables the brain to focus on relevant information while ignoring the irrelevant, the specific mechanisms of how selective attention operates, shifts, and

sometimes fails are not fully understood. In this context, this chapter investigates various aspects of selective attention to gain a deeper understanding of this phenomenon. The chapter explores potential factors that may facilitate selective attention in humans and its potential impact on our daily task performance.

Chapter 3 illustrates the importance of modality and congruency in relation to targets and distractors in the context of understanding selective attention. Effective task performance hinges on the ability to focus on the target while ignoring distractions. Research on the Perceptual Load Theory, which involved independent tasks employing both visual and auditory modalities, has indicated that under low-load conditions, both distractors and the target are processed, whereas under high-load conditions, distractions are not processed. The study reported in this chapter extends these findings by examining the impact of cross-modality (involving targets and distractors from different sensory modalities) and congruency (the similarity between the target and distractor) on selective attention using a word-identification task. Various parameters were analysed, such as response time, accuracy rates, the congruency of distractions, and subjective reports of cognitive load. In contrast to prior research on Perceptual Load Theory, the results of the current study reveal that modality (specifically, the congruency of distractors) had a significant influence, whereas cognitive load had no impact on selective attention. This chapter underscores the significance of considering subjective measurements of cognitive load when investigating perceptual load and selective attention.

Chapters 4 and 5 delve into the linguistic characteristics of stimuli and how they impact participants who possess a variety of expertise in a specific variant of a script. These chapters are based on the 1971 through the Kerala government's script reform act which led the official transition of the Malayalam language script in India from Traditional Script (TS) to Reformed Script (RS). Consequent to the shift there are two distinct groups of readers today: TS experts, who were educated to read and write in the pre-reform TS, and RS experts, who were taught to read and write in post-reform RS exclusively. The study reported in chapter 4 investigates the concept of two distinct levels of orthographic knowledge, namely lexical and sublexical, and explores how these levels are influenced in the context of the Indian language Malayalam, which underwent a script reform in 1971. Through reading and writing tasks, I compare the performance of elderly participants who acquired literacy in the traditional script, characterized by complex ligatures, with that of younger participants who gained literacy in the reformed script, which features simpler glyphs. Both groups read text more swiftly in the reformed script, indicating that script simplification had a beneficial effect. When it came to writing, the elderly participants predominantly utilized the traditional script, while the younger ones employed the reformed script. A significant contrast is observed in the functioning of orthographic expertise when it comes to different versions of the Malayalam script. This chapter offers evidence from a non-European script that orthographic knowledge indeed comprises two separate yet interconnected levels. Even though a script change impacts both of these levels, the sublexical level appears to be more resistant to change, possibly due to fewer opportunities for updates.

Chapter 5 focuses on the recognition and processing of letters, non-linguistic visual stimuli, by novices and experts of Malayalam orthographic knowledge. The majority of reading research has traditionally concentrated on three primary levels: letters, words, and sentences. Letters are the script symbols that encode human speech sounds, enabling the graphical representation of words and the construction of sentences using written words. Consequently, reading a script involves visually processing the letters within words and sentences, decoding their sounds, and pronunciation. Surprisingly, TS experts, despite consistently choosing TS for writing, read sentences in RS faster than sentences in TS. This contrasts with the expectation that TS experts would read TS sentences faster, akin to RS experts reading RS sentences faster.

To investigate whether and how the complexity of letter-level features in both TS and RS influences reading fluency across participants who are experts and novices in their respective scripts, this follow-up study was conducted utilising the orthographic knowledge theory's two levels. The findings indicate that both TS and RS experts, as well as novices in both scripts, were quicker in recognizing TS letters compared to RS letters. This suggests that reading fluency and the two levels of orthographic knowledge should not be generalized across the three reading levels. Furthermore, this implies that expertise in reading sentences in TS or RS does not necessarily imply expertise in subsequent letter-level reading.

Behavioural experiments discussed in the thesis, are typically carried out under controlled laboratory conditions which may not fully capture the real-time dynamics of attention processes but gives us an improved understanding of selective attention with respect to the mostly unexplored parameters discussed in the thesis. In summary, the research on selective attention presented in this thesis contributes to our improved comprehension of how people manage and sift through information in their daily lives.

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Abbreviations

PLT: Perceptual Load Theory

CLT: Cognitive Load Theory

RT: Response Time/ Reading Time

MEG: Magnetoencephalography

TS: Traditional Script

RS: Reformed Script

ERP: Event-Related Potential

EEG: Electroencephalography

ITD: Interaural Time Differences

LD: Learning Disability

VT: Visual Task

AT: Auditory Task

mTRF: Multivariate Temporal Response Function

NASA TLX: National Aeronautics and Space Administration Task Load Index

P1: Name of a cortical evoked potential

Chapter 1.
Introduction: Overview of the Thesis

We experience the everyday world as sights, sounds, smells, tastes, and textures through our visual, auditory, olfactory, gustatory, and tactile sensory perceptions, respectively. The object of perception, detected through these senses, is called **perceptual stimulus**. We gather the perceptual information about the stimuli from the different sensory organs and integrate and organize this information in our brain to make a coherent whole picture of the objects around us. This allows us to learn about the world and engage with it effectively. Engaging with the world to attain an intended result is called **performing a task**. Our sensory perceptions are constantly sending perceptual information about many perceptual stimuli to the brain, but not all of it is relevant or useful for performing a task. This is a problem because processing of the perceptual information requires the brain to engage its resources, however these resources are limited. Since it is impossible for the brain to process all the information, it must choose to focus its resources on only the relevant aspects of the stimuli (Kahneman, 1973). **Selective attention** is the cognitive process that allows us to filter out not only the irrelevant aspects of a stimulus of interest, but also block the entire irrelevant stimuli, called **distractors**, from getting processed.

Even though selective attention has been identified as a possible mechanism which allows the brain to attend to the relevant information while ignoring the irrelevant information, the details of how selective attention engages, disengages, and in some cases fails, are not very well understood. In this direction, the present study examines some aspects associated with selective attention to gain a better understanding of the phenomenon. The study explores some parameters that could possibly be the reasons enabling selective attention in humans and its possible effects on our everyday task performance. In the next section I discuss important terms and concepts related to attention and task performance.

What is Selective Attention?

Attention is an active and multi-level cognitive function. It allows for detecting the perceptual stimuli and interpreting perceptual information from them. It has an initial, lower level (i.e., at the level of senses) of processing, where the perceived stimuli are categorized as relevant and irrelevant, automatically and unconsciously, on the basis of perceptual information. Whatever is categorized as relevant at this level, is then 'focused' on for further interpretation at a higher-level (i.e., level of consciousness) of attention on the basis of intentions, prior knowledge, expectations, etc.

Attention can be broadly classified into four subtypes: a) Sustained Attention, which is the ability to focus on a specific stimulus or task for a prolonged term with minimal distraction; b) Selective Attention, which is the ability to control perception or allocate attention to relevant or irrelevant stimuli c) Alternating Attention, which is the ability to shift focus amongst tasks or stimuli of different cognitive requirements d) Divided Attention or Multitasking, which is the ability to focus on multiple tasks or requirements of the stimuli simultaneously (Pashler, 1998, 2004).

Selective attention is considered crucial in all our goal-oriented behaviours as this requires attention directed towards 'goal relevant stimuli' while ignoring 'irrelevant stimuli' or 'distractors.' For the past many decades, the debate on selective attention is not over the idea of this concept, but over the locus of attention, i.e., the point at which the segregation or selection of stimuli happens. According to (Lavie et al., 2004), selective attention can be divided into two mechanisms:

a) Perceptual Selection Mechanism (PSM): Under PSM, in situations of high perceptual load, irrelevant stimuli or distractors are prevented from perception. This is a passive mechanism. In tasks with a high perceptual load, the distractors are blocked from perception as there are insufficient resources to process them.

b) Cognitive Control Mechanism: This is a more active mechanism in situations of low perceptual load. The cognitive control functions identify the relevant stimuli and reduce the interference from the already perceived irrelevant stimuli or the distractors affecting the desired goal of the task. According to these two mechanisms, selective attention allows individuals to focus on task-relevant stimuli and prevents the processing of distractors to a large extent. The underlying cognitive and neural mechanisms of selective attention are still key topics of investigation.

Theories of Attention

Attention in cognitive theories is considered to be an exhaustible element in perceptual processing. Because of its exhaustibility, attentional theories are interested in the system of selection of what it gets engaged in. Most of these theories, therefore, are about the allocation of attentional elements to achieve the desired goal. According to the prominent theories in this field, voluntary control of perception is limited to selecting or identifying the priorities in distributing/dividing attention, i.e. segregating attention between relevant and irrelevant stimuli. According to Benoni and Tsal (2013a), the queries that these theories deal with can be broadly classified into two: a) at which stage in the information processing stream does attention select information? b) to what extent are unattended stimuli processed? The theories exploring these queries are classified into the following domains:

Early Selection Theories

This idea was initially developed by Donald Broadbent, which led to his "Filter Model" in the late 1950s (Broadbent, 1966). He used an 'information-processing metaphor' to define human attention. He explained that in our perceptual process, the selection of relevant information occurs 'early on' as our information processing capacity is limited. This could be achieved by using a filter that would determine the relevant information from the non-desirable ones. He claims that all the stimuli received are initially scanned based on their physical attributes, such as size, colour, location, pitch, and others. The 'filter' then gives access to some stimuli to pass through while rejecting others.

Another theory on early selection is on 'Selective Visual Attention,' there are two subtypes to this: a) Spotlight Model: Here, the visual selective attention is compared to that of a spotlight. William James (James, 2007) suggested this, and according to him, this model has a 'Focal Point' as the core where things are viewed with extreme clarity. This core is followed by an outer layer called the 'Fringe', where things are visible but not as clear as the core part. The outermost layer is named the 'Margin', where the incoming stimuli are invisible. b) Zoom-lens Model: This model works like the zoom lens of the camera. The capacity to increase or decrease the focus on the incoming stimuli depends on the viewer (Mueller et al., 2003). But when the area to focus on is wider, the processing of information takes place at a slower rate and vice-versa. This again emphasises that the attentional resources or the perceptional capacity available are limited.

Another theory used by the early selective attention theorists is based on the 'Dichotic Listening Studies' or the 'Selective Auditory Attention Theory.' This is based on the 'Cocktail Party Scenario.' How is it that at a party, we can selectively listen or engage in a conversation by ignoring the explosion of stimuli bombarded towards us? This selective auditory attention was tested using the Dichotic Listening tasks (Cherry, 1953; Moray, 1959). Two auditory messages, one each for the ears, were presented simultaneously to the participants. In the end, the participants were asked to repeat those auditory messages. They were able to recall and repeat one of the two auditory inputs clearly. The participants couldn't recall the content of the unattended or ignored auditory input but were able to recall some of the physical attributes of the input, such as the pitch, a man's or a woman's voice, and the language in which the input was given.

An alternative model in selective attention was proposed by Anne Treisman (1969), known as Treisman's 'Attenuation Model.' She conducted the dichotic listening tasks by presenting two separate stories, one to each ear at the same time. The participants were informed about recalling one of the stories presented. But, in the middle of her experiment, she switched the stories between ears. She found that the participants, too, immediately switched their attention to the one auditory signal/story that they were previously listening to. The results of this experiment propose that we are mostly inclined towards meaningful information, though there is no voluntary involvement in their selection. This also suggests that we do monitor messages named 'unattended'/ 'Irrelevant' to some extent, depending on their meaning. This implies that the Filter theory is not completely true. The unattended or irrelevant stimuli do not get completely blocked at the physical attribute stage. The selection of relevant stimuli or the filtering of information starts with the physical attributes and slowly gets attenuated depending on their semantic efficacy. This theory, thus, proposes attenuation rather than blockage of unattended stimuli. This attenuation also explains why it is possible to listen to our own names in the array of unattended stimuli. In this case, attenuation strengthens the unattended stimuli towards perception.

Late Selection Theories

The late selection was proposed by Deutsch and Deutsch (1963). This model indicates that the unattended information or the irrelevant stimuli, rather than getting filtered out at the physical attribute stage, processed to move further to a semantic level along with the relevant information. Following this, stimuli that are relevant go to the 'conscious awareness' level, which yields the desired task response. This model intersects with the remarkably interesting yet weird idea of 'Subliminal Perception' (Ionescu, 2016; Kido & Makioka, 2015). Subliminal perception is the idea of us not being completely aware of what gets processed out of all the stimuli we attend to. The perception in this model is involuntary, and the threshold of perception is the area of discussion. The question here is about those stimuli that get semantically processed yet do not reach the realm of conscious awareness. How much do these kinds of stimuli influence our actions, ideas, and emotions? This is an interesting area of psychology, and researchers are working on the validity of such a phenomenon. The challenge of establishing and operationalising the 'Threshold of awareness' and the subjectivity of perception or selective attention are key areas of research (Bargh & Morsella, 2008; Daneman & Merikle, 1996; Greenwald, 1992). One of the ways in which this could be achieved is through analysing the behaviour of human beings when they process stimuli in the form of tasks.

Theoretical Frameworks

In this section I shall describe the three frameworks that I have used in this thesis. Two of these, i.e. the Perceptual Load Theory and Cognitive Load Theory directly deal with attention. The third one, the Orthographic Knowledge is a theoretical framework that connects linguistic knowledge with attention.

Perceptual **Load Theory**

Nilli Lavie's model (2004; 1994) offers a potential resolution to the longstanding 'early' versus 'late' selection debate in attention research. By examining the historical track of evidence supporting early selection from the 1950s and the subsequent shift towards favouring the late selection model from the mid-1970s onward, Lavie and Tsal (1994) argued that these conflicting findings could be attributed to methodological disparities. They highlighted the predominant use of filtering paradigms in earlier studies, such as dichotic listening tasks pioneered by Cherry in 1953 (Cherry, 1953). These tasks imposed a substantial cognitive load on participants by presenting multiple stimuli, aiming to assess how attention copes with overload and which stimuli are selectively processed or ignored. In contrast, later studies adopted alternative approaches like the 'selective set paradigm,' which presented participants with a more manageable amount of information, typically a single target and distractor. This shift in methodology aimed to reduce the demands on attention.

From these observations, Lavie and Tsal (1994) deduced that the crucial factor influencing these divergent conclusions is the 'perceptual load' of the task. Early selection occurs in high perceptual load conditions that exhaust cognitive capacity, leading to the non-perception of unattended items. Conversely, in low perceptual load conditions, where attentional demands are reduced, late selection takes place, allowing the perception of unwanted information.

Central to Lavie's perceptual load model is the assertion that selective attention is constrained by capacity, aligning with the early selection view. However, perception proceeds automatically and involuntarily for all stimuli within this capacity limit, even if they are irrelevant to the task, resembling the late selection view. This implies that under conditions of low perceptual load, where spare capacity exists, the processing of task-relevant stimuli spills over into the processing of irrelevant information. The model suggests that refraining from processing irrelevant items is only possible when the relevant capacity is fully consumed. Conversely, in tasks with high perceptual load, all processing capacity is dedicated to the processing the target in the task, leaving no surplus capacity for the processing of irrelevant information.

Cognitive Load Theory

Cognitive load is the amount of information our working memory can hold on to at a specific interval of time. Cognitive Load Theory was modulated and developed from the prominent 'Human Processing Model' by Richard Atkinson and Richard Shiffrin (1968). The model was divided into three parts – a) Sensory Memory, which receives the incoming information, some of which is then passed on to the second part, i.e., b) Working Memory, where the information is encoded and later retrieved for relevant processing. The encoded information then moves to the c) Long-Term Memory, where, based on the information, schema formation and automatisation occur. The present structure to Cognitive Load Theory was proposed by John Sweller (1988). Working Memory is considered to have a limited capacity (Miller, 1956) and can retain only a minimal number of chunks of information at a defined period of time. Sweller emphasised effective learning by urging instructional frameworks to avoid overloading working memory with additional chunks of information which is irrelevant to learning.

Cognitive Load Theory was developed as an effort to give empirical guidelines for instructional designers to increase the relevant schema formation in learners. Cognitive load is broadly classified into three types:

Intrinsic Load: This refers to the number of cognitive resources essential for an individual to process the new incoming information and then transfer it to long-term memory. The cognitive resources are driven by the executive functions of the brain, such as attentional control, cognitive flexibility, cognitive inhibition, and others. Here, the nature of the new information plays a crucial role in their processing, i.e., the complexity or subject matter of the incoming information. The instructor does not play a key role in Intrinsic Load.

Extraneous Load: The additional information that occurs along with the incoming information. The extra information comes mostly through the instructions. Here, the load is mostly induced by the instructor or an external factor, and the subsequent instructions either promote or limit learning. According to Chandler and Sweller (1991), certain effects are caused by the extraneous load: (1) Visual split-attention: This happens when a poorly designed text is used for instruction. The same modality (e.g., Visual) defines multiple information within a framework. This ultimately leads to a high visual cognitive load. (2) Auditory Split Attention: Split attention is caused by the high auditory cognitive load. These split attention effects are not conducive to learning.

Germane Load: This is the load induced by the processing and construction of incoming information and the automatisation of schemas. Increasing Germane load is an indication of better learning through increased schema construction. Reduction in extraneous load would provide enough working memory capacity to redirect learners' attention towards processing relevant information.

Orthography and Orthographic Knowledge

Orthography, which literally means 'accurate writing,' comprises the written aspects of languages, including writing systems, scripts, spelling, and punctuation rules. Its primary focus lies in the conventions that link spoken language to its written script, composed of visual symbols used to represent the spoken word (Apel et al., 2019). As an academic discipline, orthography holds a unique position, drawing insights from diverse fields like linguistics, typology, psychology, and the study of reading and writing (Cassar, 1997; Cunningham, 2006; Geva & Willows, 1994). From a societal and policy perspective, orthography holds great significance as it constitutes a fundamental component of literacy acquisition. Despite its profound influence on various research domains, orthography has encountered challenges, such as inconsistencies in defining and measuring its concepts. Furthermore, substantial research on orthographic studies has been centred on English and European languages, which has resulted in a notable lack of diversity in the field's data (Padakannaya et al., 2022; Vaid & Padakannaya, 2004).

Orthographic knowledge refers to the ability to interpret spoken language when it is presented in written form (Apel, 2011; Masterson & Apel, 2010). This includes various aspects of a writing system, including letter shapes, letter and grapheme configurations (such as Roman letters compared to Devanagari), the formation of syllables or characters, diacritics or circumflexes, word composition (whether they are simple or compound words), spatial relationships, and syllabic structure. A grapheme is the smallest functional unit of a writing system or script. These elements have a significant impact on the cognitive processes of individuals, affecting their thinking, reasoning, recognition of stimuli, concept formation, and worldview. Consequently, there is a connection between the different components of language, the cognitive processes related to language comprehension, and how language is visually represented (orthographic form or script). The mental representation of orthographic knowledge reflects the external linguistic system of a given language.

Orthographic knowledge can be further categorised into two types: lexical orthographic knowledge and sublexical orthographic knowledge. Lexical orthographic knowledge refers to the set of words or word parts an individual already knows (Apel et al., 2019). Sublexical orthographic knowledge involves understanding the rules or patterns that connect graphemes to sounds or affixes and the rules governing the occurrence of graphemes in relation to each other and their positions within words. These two types of knowledge do not have a strict hierarchy, despite their names suggesting otherwise, and they are employed in different reading and writing contexts. Known and familiar words, falling under lexical orthographic knowledge, are read and written with ease and minimal cognitive effort. When encountering unfamiliar words not stored in one's lexical orthographic knowledge, sublexical orthographic knowledge comes into play (Apel et al., 2019).

A commonly used task to measure orthographic knowledge in studies is the orthographic choice task (Cassar, 1997; Ehri, 2014). In this task, participants listen to a word spoken by the experimenter and are then asked to match it with one of two written words in a word pair. The words in the word pair may consist of a correctly spelt word, an incorrectly spelt but orthographically plausible version of the correctly spelt word (e.g., "brain" vs. "brane"), or a homophone (e.g., "pear" vs. "pare"). This task assesses an individual's lexical orthographic knowledge in the form of their stored mental representations of word spellings. Current theories and research suggest that lexical and sublexical orthographic knowledge are independent but interconnected concepts (Apel, 2011; Apel et al., 2019; Wolter & Apel, 2010). When we tested orthographic knowledge of scripts, we also tested how participants selectively process assigned tasks across their three levels of reading - letters, words, and sentences (Refer to Chapter 4 for detailed description). Fewer studies are testing the effects of the linguistic nature of tasks, specifically biscriptality, on selective attention (Vaid, 2022a). A mostly unexplored domain in testing orthographic knowledge among readers and writers of a script is the biscriptality of the participants. More than half the population around the world speaks more than one language, and the world has more bilinguals than monolinguals (Grosjean, 2010; Tucker, 2001). Biscriptality is when two or more writing systems are used within a language. Even in bilingual selective attention studies, monoscriptal bilingual studies take precedence over biscriptal studies. We have tried to bridge the gap between monoscriptal selective attention studies by designing reading and writing tasks in Malayalam orthography and its two existing variants of scripts. Biscripatality is not just a linguistic function but also as an important factor that might influence selective attention amongst other cognitive functions (Vaid, 2022b). The results from the studies comparing biscriptal participants would help us understand how orthographic knowledge and selective attention control the linguistic skills as well as the problem-solving skills. Though not directly related to bilingualism and the other linguistic theories prominent at the moment, the late selection views of selective attention research did use linguistic inputs such as the dichotic listening tasks (Lipschutz et al., 2002; Moray, 1959; Onoda et al., 2006) to test the automatic and extent of stimuli processing. Linguistic stimuli were the medium to study whether the stimuli were getting processed more than their physical attribution stage.

Research Gaps

This thesis looks at other aspects that might affect attention to understand the intrinsic nature of selective attention. They are the nature of the participants, modality and domain of the tasks, and differences in the available attention factors, which would include 1) expertise; 2) multiple modalities involved in the perceptual stimuli; 3) linguistic and non-linguistic aspects. Thus, as complexity or 'load' induced by tasks is majorly what PLT looks at, this study tries to look at aspects of 'Types of participants' and 'Types of tasks' and their effect on selective attention.

In this backdrop, I took up studies to answer some questions mentioned here. The following **conceptual question** collates the information from the research done previously in the form of the literature review which:

1. What is load and selective attention as referred to in the field of cognitive sciences, especially the Perceptual Load Theory?

The current chapter has attempted to answer the above question by looking at the definitions and instrumentalisation of selective attention in Perceptual Load studies and its interlinked concepts, such as Cognitive Load Theory and Orthographic Knowledge.

The following **experimental questions** are answered through experiments and data collection:

1. Does the nature of the task interact with selective attention? The nature of the task refers to whether the task was linguistic or non-linguistic.
2. Does the modality of the task affect selective attention? It helps to understand how selective attention functions with different types of tasks, e.g., visual vs. auditory tasks.
3. Does the type of participant play a role in the management of load and attention? Do experts, compared with novices or typical learners compared with learners with learning disorders (LD), use attention the same way?

Brief Overview of Chapters

Chapter 1:

Chapter 1 introduces the basic concepts associated with attention. The chapter explores early and late selection theories, introduces the theoretical frameworks of the thesis, and establishes the foundation for the research gap and the ensuing questions addressed in this thesis.

Chapter 2:

Chapter 2 attempts to conceptually capture major theories and important research done to decipher selective attention in human beings and further collates pertinent research done on selective attention with a focus on Perceptual Load Theory. The chapter also tries to understand better the two most common and frequently used, yet subjectively defined terms in selective attention studies - Load and Task. To get a better understanding of the existing concepts in selective attention, cognitive load theory and its possible association with Perceptual Load Theory is explored.

Chapter 3:

Chapter 3 explores the second research objective, i.e., the effect of modality, if any, on selective attention tasks. Successful performance of a task relies on selectively attending to the target while ignoring distractions. Studies on Perceptual Load Theory, conducted involving independent tasks with visual and auditory modalities, have shown that if a task is low-load, distractors and the target are both processed. If the task is high-load, distractions are not processed. The current study expands these findings by considering the effect of cross-modality (target and distractor from separate modalities) and congruency (similarity of target and distractor) on selective attention, using a word identification task. Parameters were analysed, including response time, accuracy rates, congruency of distractions, and subjective report of load. In contrast to past studies on PLT, the results of the current study show that modality (congruency of the distractors) had a significant effect, and load had no effect on selective attention. This study demonstrates that subjective measurement of load is important when studying perceptual load and selective attention.

Chapter 4:

Chapter 4 explores the first and third research objectives, i.e., the interaction between the linguistic nature of tasks and selective attention and between participant type (experts or novices) and their management of load and selective attention.

To understand the linguistic nature of tasks and selective attention, we explored the idea of the two levels of orthographic knowledge, i.e. lexical and sublexical; in particular, how these levels are affected in the case of the Indian language Malayalam that went through a script reform in 1971. Through reading and writing tasks, we compare the performance of elderly participants who gained literacy in the traditional script (with complex ligatures) with younger participants who gained literacy in the reformed script (with simpler glyphs). Elderly participants are, therefore, experts in traditional script compared to younger participants who are novices in the traditional script but experts in the reformed script. Both the groups read text faster in reformed script, indicating script simplification was beneficial. While writing, the elderly participants largely employed the traditional script and younger ones used the reformed script. The study provides proof from the non-European alphabet that orthographic knowledge indeed has two independent but related levels. Although a change in script affects both levels, the sublexical one seems more resistant to change, possibly due to fewer opportunities to update it.

Chapter 5:

Chapter 5 explores objectives on nature of the task, i.e., non-linguistic as well as linguistic nature of the task and its interaction with participant type. We are also looking at how the expertise in a script and being a novice in the same script affects reading and thereby selective attention. To further understand how the complexity of features at the letter level affects fluency in reading, we conducted this follow-up study where fluency in reading TS and RS is being analysed at the letter stage by having the same graphemes in TS and RS used in the preliminary study. To rule out the effect of expertise on letter perception having an impact on the letter recognition task, we incorporated two types of participant groups. Group 1 had participants who were experts in reading Malayalam TS and RS graphemes, and Group 2 had participants without knowledge of Malayalam graphemes. This study looks at the questions of reading fluency across its three levels - letters, words and sentences. The study further explores whether the three levels of reading have a common base of orthographic knowledge, or they vary when readers proceed from one level of reading to the other, i.e., letters to words or words to sentences in a language. The study provides proof that fluency in letter recognition TS letters is because of the better retrieval of lexical orthographic knowledge of the TS letters presented in the experiment. But when the letters in the same words are read non-fluently, does it mean that the lexical orthographic knowledge associated with the letters is different compared to that of the words?

Chapter 6:

This chapter brings all the research threads together and provides the overview of the answers found through the studies reported in this thesis. The chapter also discusses the limitations as well as suggests the future scope of research that can explored in this domain.

Chapter 2.
Tasks and Load in Selective Attention Studies – Literature review

What is Perceptual Load?

Yantis and Jonides (1990) introduced a hybrid model of selective attention. This model had a variable locus of attention. According to their model, the filter used in the perception of relevant stimuli from the irrelevant batch is not constant and moves based on the nature of the tasks. This contrasts with the views of the 'Early' vs. 'Late' selective attentional theorists and their claim on the location of the attentional filter in the perception of stimuli. Lavie and Tsal (1994) adapted this idea and developed the 'Perceptual Load' theory. They tried to identify the factors that determined the movement of the filter. According to the Perceptual Load Theory, "Perception is a limited capacity process and proceeds automatically until that capacity is filled." This means that when a task induces a heavy perceptual load or exhausts the processing capacity, the irrelevant stimuli or the distractor do not get processed, and a desired goal or performance is achieved. This is in accord with the proposed 'Early' Selection views of perception. In the case of low perceptual load, the Perceptual Load Theory is more aligned to the 'Late' Selection views of processing both the distractors and relevant stimuli to the point of exhausting this limited processing capacity. This means that the distractor interference in the case of tasks with low perceptual load is high and may not result in the desired performance.

According to PLT (Molloy et al., 2015), 'attention refers to allocating limited-capacity mental resources to processing.' Hence, PLT tries to understand the process of selective attention and the extent of irrelevant and relevant distractor processing. The extent of stimuli recognition in each task depends on the perceptual load in the task. The processing capacity limits are reached 'early' if the perceptual demand of the task is high and 'late' if the perceptual demand is low(Lavie et al., 2004). PLT also urges us not to confuse the concepts of attention and intention (Lavie et al., 2009). During a task, even if the instruction is given to the participants to ignore certain aspects of the stimuli, the stimuli rendering happens to a certain extent. The instruction to ignore task-irrelevant information is not sufficient to leave the stimuli unattended. According to the hybrid perceptual load model in PLT (Lavie, 2010), attention is an automatic process. Unless the task involves a high perceptual load, attentional resources will automatically spill over and perceive the irrelevant aspects of the stimuli. The load theory fails to give a precise definition of load. There is always circularity in the way load and allocation of attentional resources are defined (Benoni & Tsal, 2013a). The task is considered a high perceptual load task when the distractors or the irrelevant information do not get processed, and the task is considered a low load task when the attentional resources spill over and process the distractors. On the contrary, perceptual load, based on multiple studies, has been operationalised by multiple methods. One of the ways was to alter the number of items in perceptual recognition tasks, i.e., a larger number of items on display would increase the complexity of the task. Another way was to alter the number of operations to be performed in a task; multiple perceptual operations in a task increase the complexity of the task. Some studies also have operationalised perceptual load by increasing or decreasing the similarity between relevant and irrelevant aspects of the stimuli. Multiple study results support the Perceptual Load Theory, and they have found that the perceptual demand induced by the task determines the allocation of attentional resources. The results confirm that high perceptual load tasks do not process the irrelevant aspects of the stimuli. High perceptual load task significantly reduces the amount of irrelevant information that gets processed (Lavie et al., 2009; Lavie & Cox, 1997; Macdonald & Lavie, 2011). This evidence in support of the Perceptual Load Theory is predominantly from the visual domain. The question of whether the results pertaining to visual modality and visual perception would hold true for auditory perception still remains. The juxtaposition of results from the visual perceptual load studies to auditory modality would not be accurate due to its evolutionary nature. Hearing is often considered the ‘early warning system’ for the ‘fight or flight’ response of human beings (S. Murphy et al., 2017). This evolutionary difference in the way our senses, vision and hearing function in the real world implies a difference in the way the distractors might get noticed or processed. The difference in modality might also affect the way in which perceptual load affects target identification and distractor processing.

Role of Distractors

The theory of Perceptual Load revolves around the role of distractors or irrelevant stimuli. The whole idea of high perceptual load and low perceptual load operationalises the definition of distractors. Forster and Lavie (2008) classified distractors into two types: a) Relevant Distractors and b) Irrelevant Distractors. The relevant distractors are the ones that are extremely similar to the target or the desired response. In Lavie's study, in a letter search task, type A distractors are the ones that are also letters but different from the target letters. Type B distractors are the ones that are truly irrelevant compared to the target response, such as cartoon characters. Here, type A distractors are also competing towards the desired task response. But Lavie states that the nature of distractors is irrelevant in case of high perceptual load, as the type of the distractor or the response-competing qualities of the distractor did not have any impact on the desired response.

However, studies do show how the nature of the distractors causes task interference even under high perceptual load. One of the major studies which state this is the "Special Case" of faces (Farah et al., 1998; Renzi, 2000). Evidence from neuroimaging studies in this field indicates that a specialised module processes human faces compared to other stimuli. The interference was higher when the distractor was a known face. The high perceptual load – less distractor interference theory was ruled out in this scenario. There are studies that divide attention capacity based on the interference caused by faces into a) Face Capacity and b) Non-face Capacity (Thoma & Lavie, 2013). According to these studies, face and non-face distractors had different interference rates in the load studies. Lavie suggests that by utilising the entire attention module available for facial processing, the suggestions and predictions of load theory can be sustained. The entire special case of facial processing is challenged by the case of expertise in the desired target field. The processing of a distractor better than the other in any field could be because of the participants' expertise in the particular field tested (Gauthier et al., 2000). Familiarity and expertise might be the two major elements that result in distractor interference in an assigned task (Krasich et al., 2019; McClelland & Chappell, 1998).

Auditory Selective Attention and Perceptual Load

In the next two sections of this chapter, past studies on Perceptual Load have been analysed to understand selective attention in the contexts of auditory and visual modalities. Many perceptual load studies (Cartwright-Finch & Lavie, 2007; Lavie, 2010; Lavie & Dalton, 2014) have established selective attention to function independent of modality, and some others (Dalton & Hughes, 2014; Deng et al., 2019; Fairnie et al., 2016; S. Murphy et al., 2017) have shown selective attention to be modality dependent. These sections discuss how load has been defined and actuated in Auditory and Visual selective attention studies separately. Auditory perception has not been studied extensively like the visual modality in the Perceptual Load Theory framework. The manipulations of auditory stimuli in perceptual load studies are a direct replication of load manipulations carried out in visual perceptual tasks. This replication of visual load manipulation parameters on auditory stimuli can be classified into three categories: a) Increasing the complexity of the stimuli, thereby increasing perceptual load by fluctuating the number of items in the display of the task; b) altering the similarity between targets and non-targets or distractors and c) by increasing or decreasing the perceptual operations required to perform a task. Apart from these three categories, there are studies that have tried not to imitate load manipulations carried out in the visual domain and has tried to incorporate other techniques to manipulate load to understand auditory perception. This section, therefore, attempts to understand the effect of auditory modality on selective attention based on multiple tasks that were recently designed for various studies in this field. This is essential as auditory perception has not been studied extensively like the visual modality. The following sections have tried to apply the parameters prevalent in the visual domain to the auditory domain, which were used to define load under the framework of perceptual load. This gives an opportunity to compare the mechanisms of distractor processing in both the visual and auditory domains and whether the load induced by tasks would affect selective attention in the same way in hearing as compared to vision. Some perceptual load studies have established selective attention to be independent of modality. However, mixed results both for and against perceptual load in the field of hearing probes further investigation in this domain.

Number of Perceptual Operations Required by a Task

The first category is based on the complexity of the task. The complexity determines the load induced in a task based on the number of operations a participant would have to perform in a particular auditory task. For this, some studies have tried to map the perceptual demand of a speech stimulus (both target and distractor speech) and auditory perception. The results of these studies mostly align with the existing Perceptual Load Theory, stating that during a task with low auditory perceptual demand, the distractor speech sounds get better representation in the human cortex. A recent study shows that there is better segregation of distractor speech when the perceptual demand is low (Hausfeld et al., 2021). This study tested the processing of distractor speech while selectively listening to the target speech. It was tested whether, in the context of natural speech, a low auditory perceptual load increases the distractor interference, i.e. the processing of distractor sounds increases with the load of the task. This would then reflect in the cortical segregation of the distractors. The perceptual demand was altered from low to high by manipulating the interaural time differences (ITD) of distractor speakers as compared to the target speaker. ITD manipulation is a way of altering the perceptual demand by changing the interstimulus/stimuli intervals. This altering of perceptual demand had an effect on the behavioural performance of the selective listening task. EEG and mTRF modelling were used to confirm the effectiveness of the perceptual manipulation. There was a higher cortical segregability of the distractor speech when distractors had higher ITD cues. The higher distractor segregability is an indication of higher distractor processing. Unlike the studies that manipulated the perceptual demand by varying the similarity (acoustic similarity) between the targets and distractors of the auditory stimuli, this study manipulated the acoustic cues or the inter-stimuli time, leading to a higher or lower perceptual demand. To have conclusive evidence on the effect of perceptual demand on auditory perception, the study examined ITD's specificity on frequency bands, scalp locations, and timing. The results on these parameters show that the perceptual demand had an effect that was due to the early processing window neural responses (0-200 ms) and low frequencies (0.5-4 Hz) of the EEG signal. These results are again in line with past visual and auditory perceptual demand study results, where the distractor processing is affected early on according to perceptual demand posited by the tasks. On the contrary, a study by Melara (2021), shows low auditory attentional disruption in ERP analyses under low perceptual demand. Thirty-two participants were tested in an auditory task paradigm, which is a task with a variation to the existing flanker task. The auditory stimuli were manipulated to alter the perceptual load by changing the perceptual pitch distance between targets. Frequency-wise, 1200 Hz separation was for the low auditory perceptual load, and 800 Hz separation was for the high auditory perceptual load. The study measured the auditory distractor interference on the early (P1) versus late (RP) selection using the ERP components. The results of the study showed a higher attentional interference by the distractors when the high auditory perceptual load task was compared to the low load task. This remained constant across the three analyses of load conditions designed in the study - Garner interference tested between tasks, which reflected in the participants' accuracy scores and RT, Flanker congruity tested between stimuli, which reflected in the participants' accuracy score; and Graton effect tested between sequences again reflected in the participants' accuracy scores. The ERP analyses of the participants' behaviour scores showed a higher disruption in P1 in the auditory attention task when the load was high as compared to the low load task. These results differ from the existing results from the Perceptual Load Theory.

Alternate Auditory Load Manipulations

For understanding auditory perceptual load, other than following the exact replica of visual load manipulations, some studies have tried alternate auditory manipulation methods. For this, they have tried to test whether the attentional resources available for all the modalities are the same and whether the resources for one modality get attenuated when the demand for others gets higher. According to selective attention's adaptive filter model, in a visual task, filtering of irrelevant auditory stimuli happens early when the visual task is a high-load task. The filtering of irrelevant auditory stimuli happens late when the visual task is a low-load task. This was tested using auditory steady-state responses (ASSRs) in a study done by Szychowska and Wiens (2021). Research on ASSRs suggests that by varying the frequency of the amplitude modulation, there is a change in the contribution to neural generators and, thereby, in attentional filtering. This study measured the effects of cross modal attention between visual tasks and tones played simultaneously with three different modulation frequencies - 80, 40, or 20 Hz. The visual task again was subdivided into three based on the load-induced - no load, low load, and high load task. The load manipulation was measured using variables such as RTs, self-reported workload scores, and P3 (visual target versus non-targets). The results showed no alignment with the existing perceptual load results. This study showed no effect of visual load manipulations on amplitude modulation, i.e., the manipulations on visual load had no effect on the measures of the amplitude of 80, 40, or 20 Hz ASSRs. This could suggest that the pool of attentional resources available for visual and auditory processing are separate.

In a recent magnetoencephalography study (MEG), on the other hand, done by Forster and Lavie (2021), the results still align with the Perceptual load theory. This study tried to understand the facilitation of the target by suppressing the distractor. A cued spatial attention task was carried out with spatial attention tasks with varied loads and distractors with varying saliency. It was a cued discrimination task with two face stimuli presented with some eye movement in the face stimuli along with some background noise where the participants were asked to spot the direction of the eye movement. The white portion luminance of the visual stimuli flickered at 63 and 70 Hz. The results of this study showed that when the perceptual load of the task was high, there was an increase in the alpha band power. This was in line with the existing predictions of the Perceptual Load Theory. There was no increase in the alpha power contralateral to the distractor, which means no distractor interference when the load of the target stimuli was high. But when the salience of the distractor to the target was high, it led to an increased distractor alpha band power. This study, in a way, suggests that it is the load induced by the target stimuli that determines the attentional resource allocation, which modulates the processing of targets and distractors.

Altering task complexity by changing the number of items in the display

Studies on the visual domain have tried to manipulate the bottom-up demands of the stimuli by increasing or decreasing the complexities of the task. According to PLT, when the complexity of the task is greater, there is less distractor processing. In the auditory domain, some studies have tried to achieve this change in the complexity of the stimuli by changing the duration of the tones played in dichotic listening tasks. In a similar study done by Lynch, 2021, the load was manipulated, not changing the duration of the tones in low load conditions (a fixed 200ms of 1 kHz FM tone or a white noise-burst) and changing the duration of tones for high load conditions. In the high load condition, the participants were asked to respond '1' when they heard a short - 100ms tone, '3' for a long - 300ms tone, and '0' for tones not matching the instructions.

In a second experiment in the same study, instead of dichotic listening tasks, the effect of auditory perceptual load on spatial selective attention was tested. The load was manipulated by presenting one other sound along with the target in the low load condition, whereas in the high load condition, the perceptual load was increased by adding three other sounds surrounding the target. The results of the dichotic listening experiment do not support the existing results from the visual perceptual load studies. Regardless of the complexity of the auditory task, i.e., the task being a high-load or low-load task, the distractors were processed in both experiments in this study. The results of this study also suggest that the increase in the complexity of the auditory stimuli affects the late selection argument proposed by other prominent visual selective attention studies in the field (Lavie, 2010; Lavie & Tsal, 1994) as the distractors were possessed at a later stage in the high load task.

Some other recent studies indicate a connection between the auditory and visual attentional resource pool. These studies have tried altering load in the visual modality and checked its effect on the other modality. In a multi-design study conducted by Molloy et al. (2020), which had experiment data based on dual-task, MEG, and pupillometry designs, the effect of load by varying task complexity (both audio and visual modalities) on selective attention was tested. The aims of the study were also to understand the degree of impact on hearing when the visual processing demand was high and to know whether the attentional allocation of resources is shared or exclusive to certain sensory stimuli. The results showed impairment in the strength of the auditory evoked responses when the load of the concurrent visual task was high. The data from the MEG and pupillometry designs of the study suggests that attentional allocation of resources occurs in a dynamic fashion depending on the load induced by tasks.

Load manipulation by fluctuating between the similarity between targets and non-targets

An alternate method of load manipulation followed by studies in auditory perception was to increase or decrease the task complexity by fluctuating the similarity between targets and non-targets of the study. In auditory perception, the similarity of the audio stimuli, which is the target, can differ from the distractors at various levels. Some studies have tried to manipulate the acoustic-phonetic aspect of the stimuli and subsequent distractor interference. Some other studies have tried to incorporate the linguistic processing aspect along with the acoustic-phonetic aspects of the stimuli. In a study by Yahav and Golumbic (2020), these parameters were tested to understand how individuals in a noisy place, where there is both target and distractor speech competing for attentional resources, pay attention to another speaker's speech.

This study was a dichotic listening experiment that employed neural measures to assess the level of processing of irrelevant speech. Hierarchical frequency tagging was used to understand the linguistic processing of speech. MEG was used to record the brain activity during the experiment. The participants were asked to attend to the stimuli played in one of the ears and ignore the other. The target stimulus was Hebrew speech. The task-irrelevant stimuli were played under two conditions - Structured frequency-tagging speech stimulus and non-structured frequency-tagging speech stimulus. The only difference between targets and distractors was in the order of syllables present in the speech, which either formed or did not form any linguistic structure. Data from the MEG study shows that irrespective of the task-irrelevant speech being structured or unstructured, there was an acoustic representation. The study also found a neural tracking of the structured task-irrelevant speech in the left inferior frontal cortex. This particular region plays a significant role in speech processing. The MEG data also found that task-relevant speech was significantly affected by task-irrelevant speech, irrespective of whether it was structured or unstructured. These results, in direct contrast to the load theory, show that irrespective of the perceptual load induced by the target stimuli, when the task-irrelevant stimuli were a speech, there was a competition for attentional resources and stimuli processing.

In a study by Dalton and Fraenkel (2012), the concept of inattentional deafness was tested like inattentional blindness, which most of the studies in the visual domain claim to be occurring as a result of the complexity of the task the participant is involved in, this study explored it in the auditory domain. The results showed that participants can remain 'deaf' to an 'auditory gorilla', which is a task-irrelevant distractor when the demands for attentional resources are high. In another study by Murphy et al.(2013), participants were presented with rapid sound sequences with varying similarities between targets and non-target sounds. A set of spoken letters, each stimulus of 240ms, were presented to the participants. In the high-load task, the target letter (P or T) was to be drawn from a set of six non-target letters (A, C, H, G, J, and K). In the low load condition, the target letters were to be drawn from a set of Xs, which were the non-target letters. The targets were played in a female voice. The irrelevant distractors (again, P or T) were played in a male voice. The results showed no reduced distractor interference, even under high perceptual load. This is opposite to the existing predictions of the Perceptual Load Theory.

Visual Selective Attention and Perceptual Load

The Perceptual Load Theory gets substantial support in research from the visual domain. There is a dearth of research on whether the same principles of Perceptual Load Theory hold for other modalities. The way in which targets and distractors are processed in one modality may not be replicable for other sensory stimuli. The next four sections will focus on visual stimuli manipulation and selective attention. However, studies by Molloy et al., (2015, 2018) have reported that selective attention functions uniformly across modalities, especially between auditory and visual stimuli, due to them sharing the same perceptual location in the brain. The nature of the tasks, especially what becomes a target and what becomes a distractor in different modalities, might play a significant role in allocating attentional resources. Along with the nature of the tasks, additional conditions, such as the effects of reward and familiarity, also affect distractor interference. This session is classified into four categories according to the nature of load-induced on visual tasks and discusses some other factors that, other than load, affect selective visual attention.

Altering task complexity by changing the number of items in the display

Altering the number of items on display deals with the extent of attentional resources required to be selectively allotted to the task-relevant aspect of the stimuli. The number of items on display in a task is responsible for the amount of load induced per task and the subsequent attentional resources allotted for processing. According to past studies in PLT, it is indicated that the high load tasks utilise a major chunk of the allocated attentional resources, leaving little to no spare perceptual capacity for additional information processing (Lavie, 1995; Lavie et al., 2004). This means that high-load tasks do not process distractors, or there is a high reduction in distractor interference. Other studies have also shown that the distractor interference gets attenuated not just by a high-load task but also by dilution effects, i.e., having multiple task-irrelevant (non-target) stimuli that dilute the distractors (Benoni & Tsal, 2013b; Tsal & Benoni, 2010).

In a recent study (Jo et al., 2021), which assessed the top-down control on distractor interference, two different types of trials (search and probe trials) were included. The low load condition, in the search trial, had only the target letter (‘F’ or ‘H’) with a flanking distractor. In contrast, in the high load condition, non-target letters (‘B’, ‘G’, ‘S’, ‘T’, ‘K’, ‘R’, ‘P’ and ‘V’) appeared randomly along with the target letters which were all separated by colour. In probe trials, a probe (Gabor grating) for targets, non-targets and distractors appeared on the screen where they appeared in the trial right before the one attempting. The results from the study align with the past PLT study results. A significant interference in low-load conditions was marked by the distractors. In contrast, only a negligible interference was seen under high load conditions. In another study by Plotnikov (Plotnikov, 2021), the effect of task-irrelevant stimuli (emotional faces) on perceptual load was tested. Contrary to the previous result, the participants showed a significantly lower RT for trials with distractor faces than those without. This was reflected not just in low load conditions but also with high load trials with distractor faces. This study indicated that faces, when functioning as task-irrelevant stimuli, effectively capture attention from the primary letter search task.

Load manipulation by fluctuating between the similarity between targets and non-targets

The load here is manipulated by keeping the number of items in display in a task almost the same and by varying the similarity between the features of the targets and the non-targets. In a go-or-no-go study (Matias et al., 2021), along with varying the similarity between targets and non-targets, the effect of reward history on perceptual load was tested. The study used a feature vs. conjunction discrimination cue to manipulate load on a go or no-go task. The study also tried to see if the rewards impacted the distractor interference. The go or no-go cue was a single colour feature (e.g., black cue) in low load conditions and a colour and shape cue (e.g., black colour circle cue) in high load conditions. The 'go' trial had the participants determining the black-coloured letters ('H' or 'S') while ignoring the same letters in colour red or green. Responses that were accurate and quick yielded the participants' rewards. Red distractors in half of the trials functioned as high-reward distractors, and green functioned as low-reward distractors and vice-versa for the other half of the trials. Irrespective of past study results on visual selective attention, the new parameter of distractor interference caused by the reward stimuli (high reward) on targets in the low-load and high-load conditions was statistically the same. The study suggests that even in a high-load task where no spare attentional resources are available for distractor processing, the reward stimuli (high-reward distractor) could interfere with the task.

Number of Perceptual Operations Required by a Task

This third classification of visual load depends on the number of perceptual operations to be performed to identify the target from the distractor. In a recent study (Chinchanachokchai et al., 2021), the effect of secondary perceptual tasks on ad memory was tested. The task was in a game format with a target in a specific colour and shape combination, and the task was to identify the target shape from multiple items displayed on the screen. In the low load condition, the target shapes (squares and circles) were presented in two colours (red and yellow) and for the high load condition, the target shapes were presented along with multiple similar distractor shapes and colours. Simultaneous to the task, multiple radio commercials were also played. The results of the study showed that participants who played the videogame under the low load condition had a higher recollection of the radio commercials played simultaneously. Though the study does not consider the commercials as irrelevant distractors, the radio commercials did play the role of the irrelevant distractor from a different modality (auditory) interfering with the visual task (videogame). The study results align with previous results from the field of PLT. The high-load task saw no recollection of the commercial by the participants.

In a different study on colour perception and visual awareness (Chen & Chen, 2021), the results indicate that the colour perception results under load might not be a general phenomenon and might depend on the selection history, which is similar in concept to the effects of familiarity. Selection history depends on the processing strategies (block condition) of the previous trial that affect the participants' current trial on colour determination. The results show that the participants' performance was affected by the switch condition or interleave condition (two types of trial presented in couplets). Similar studies on perceptual load have also reported the effect of selection history in colour perception (Benoni & Tsal, 2013), where the distractor processing was low when there was a block condition but not when the conditions were intermixed within a block or when the variable of attentional zoom was made constant across the conditions (Chen & Cave, 2016).

Alternate Visual Load Manipulations - Neuroimaging Studies

The above classifications of visual load manipulation and its varying results have been supported by multiple neuroimaging studies. In a neural coding study (Barnes et al., 2021) of visual stimuli, the results suggest that adaptive coding operates in a fast manner in humans, leading to a momentary focus on simpler tasks or simpler aspects of the tasks. During a high-load task with distractors, when there was difficulty in making colour and shape judgements, a preferential coding of the relevant aspect of the stimuli was seen. Researchers (Verschooren et al., 2021) have tried to distinguish between the neurocognitive process responsible for the attention switches between external attention, which is perception-based, and internal attention, which is memory-based. This is an emerging area of attentional research, and there is a dearth of research analysing this attentional switching. The current research and results in the field have evidence of a perceptual attentional switch between two domains.

The recent study results on auditory perception are still uncertain on the operational aspects of selective attention. There is a mixed pattern of results on how distractors get ignored and how selective attention functions in the auditory domain. Studies from the visual domain mostly align with the Perceptual Load Theory, where the high-load task determines the distractor processing (Cartwright-Finch & Lavie, 2007; Lavie et al., 2009). An interesting MEG study (Molloy et al., 2018) which looked at the neural correlates under high visual perceptual load, found reduced interference from the task-irrelevant sounds. The study highlights both vision and hearing have a shared computational resource pool; when one modality out of vision and hearing utilises a major portion of attentional resources, the other modality might get impaired a little, if not reduce responses to a large extent. Irrespective of the way visual load was measured or manipulated across studies, the results on distractor processing mostly aligned with Perceptual Load Theory predictions.

However, analysing the overall results from the recently selected studies on auditory perception indicates an auditory distractor interference irrespective of load. This might be due to the aspect of auditory attentional resources operating separately from other sensory systems, because of which it is considered in many theories as an early warning system. Thus, all the auditory stimuli, irrespective of being a target or distractor, might get processed until there is perceptual overload and prohibits the individual from further processing other sensory stimuli. This could be another plausible explanation for the previous study results on the 'early selection' view of selective attention showing auditory distractor interference while processing the audio stimuli, irrespective of the complexity of the task itself. This accentuates the recent demands of separating visual selective attentional studies from auditory research. Though auditory selective attention might be load-dependent, its operationalisation might be fundamentally different from that of visual stimuli selection and processing. The question of whether the pool of attentional resources remains the same for all the sensory stimuli or separate for each modality is still being pondered upon by researchers in this domain. We have tried to answer this question in Chapter 2 by bringing together these two modalities, auditory and visual, and created two cross-modal tasks imitating the real-world setting. The target and distractors co-occurred and altered between auditory and visual modalities while the participants performed the task.

Tasks In Load Theories

The definitions of perceptual and cognitive load theories depend on the nature of tasks incorporated in studies from these fields. An analysis of tasks across load theories would give an insight into how the load theories function across multiple domains such as selective attention, teaching and learning and others. It is also essential to know the nature of these tasks in detail to understand their effect on the performance of the participants. This section looks at the following aspects of tasks from the studies in the field of perceptual and cognitive load theories:

Are tasks well-defined and uniform across studies in load theories?

Though tasks play a crucial role in describing load theories, the term task itself is poorly defined in the literature (Künzell et al., 2018). Some studies in psychology consider tasks as those actions that have specific goals to achieve (Schneider & Logan, 2014). Some Cognitive Load studies define tasks as problems that require individual's attention to solve them. As tasks in studies are not defined appropriately, ambiguity arises between actions that require attention and which does not (Zäske et al., 2016). These actions which require attention are targets, and those which does not require attention are classified as distractors. Targets vary across studies in load theories and their requirement of actions from the participants. Tasks or problems keep changing with different targets. What becomes a target in one study becomes a distractor in another. The sought-out action or task in one study is not the same in another (Sweller, 2018). As load theories are built on multiple tasks, and these tasks vary from one study to the other, analysing the performance of participants becomes pertinent. The performance is usually measured on the load induced both perceptually and cognitively by the tasks and the subsequent actions of the participants. The load and performance scores of the participants become crucial, along with tasks in defining load theories.

Multiple mediums of testing tasks or problems of participants are also essential in understanding the perceptual and cognitive functions of the brain. One of the major criticisms of load theories is that most of the tasks in studies from this field are from the visual domain.

Only one modality is tested predominantly in load theories. The studies that have tried to bring in multiple modalities, two modalities at best (dual-task studies), have almost neglected the distinction between targets and distractors, i.e., which medium functions as a target and which one functions as a distractor (S. Murphy et al., 2017; Sandhu & Dyson, 2016). This ambiguity in classifying targets and distractors has an impact on performance scores. The important decision of whether the change in performance was due to the change in modality of the targets and distractors or a mere change in task/problem is not answered in these studies. In some studies, both the targets and distractors were visual or auditory in nature. As the criteria for designing the targets and distractors were not uniform, the performance of participants varied from one study to another. This makes the results on modality and task performance of participants not reliable. The conclusion is that it was not the nature of the tasks that caused the change in performance scores of the participants but the non-uniformity of the design of tasks that caused it. In future research, it should be important to incorporate multiple parameters of actions/tasks in load studies and measure performance across modalities to understand the cognitive and perceptual features of load theories. In this regard, to understand selective attention better, the tasks in experiment 1 of this study have been designed by incorporating cross-modal targets with equal levels of congruency across the cross-modal distractors. The study has tested and analysed the processing of load, target and distractors to understand the perception and cognition of the participants. Experiments 2 and 3 of this study tested individuals who varied in their level of expertise in orthographic knowledge by performing tasks that varied in their linguistic as well as non-linguistic aspects (for details, refer to chapters 4 and 5).

How was performance on tasks measured across studies?

Performance is a subjective element in the field of load theories. Performance is strictly driven by a person's training and knowledge in the relevant field. Yet, this aspect of individual differences among participants is not considered in most of the studies in load theories. The performance difference that arises due to someone's expertise in a domain is often overlooked (Cain et al., 2013; Giovinco et al., 2015; van Gog et al., 2009). The results from these studies question the reliability of the performance scores of tasks. Are these performance scores a reflection of the different tasks or just the result of having different types of participants for the study? Some studies show that the effect of distractors might also help the participants to find the targets (Kane & Engle, 2002). This proves the differences in how the tasks are measured, questioning the validity again of the effect of distractors on heavily loaded tasks. The tools and units of measuring performance on various tasks also differ in studies across load theories. Studies show that the load induced by the task and distractors did not play a major role in the performance of an expert if the task was from their field of expertise. Is this because of the familiarity effect of the task itself, or are the experts good at blocking distractors? These aspects of expertise, the effect of familiarity and the measurement of distractors while performing a task should also be incorporated for a better understanding of the load theories.

Are the results of these tasks reliable in defining and understanding load theories?

The actions in load theories are always target-oriented. This means that the performance scores are almost all the time measuring the success or failure of participants in reaching their targets. The effect of the distractors is not always measured. This does not mean that the distractors are not processed. Some studies specifically say that the participants were able to identify the distractors even if the tasks were heavily loaded tasks (Gegenfurtner et al., 2011). This raises questions about the very nature of Perceptual Load Theory and how the theory is load-centric in its approaches, i.e., how the case of high perceptual load leads to blocking of distractors and processing of targets and how low perceptual load leads to processing of distractors as well as targets leading to poor performance scores of participants. The question we need to ask here is whether the change in results of distractor processing, irrespective of the load, is because of the flaw in identifying the underlying cognitive and perceptual processes of the brain or a mere flaw in the design of the task itself. The results of these studies indicate that the attention and performance of participants are not always load-dependent (Drew et al., 2013; Greene et al., 2020). So, is the change due to the change in tasks across multiple studies? When the results from studies on the visual domain are juxtaposed with tasks from other modalities, it raises a serious reliability issue of the results. Can results from a single modality be generalised to other modalities? Are the cognitive elements for all modalities the same?

Defining and Quantifying Loads and their Loopholes

The term Perceptual Load is still speculated and mused upon. There is no operational definition for the load. There is a circularity in the way in which load is defined. The high perceptual load is defined in terms of low distractor interference and high distractor interference in terms of low load. The definition of load in cognitive theories is based on paradigms, which are based on the manipulation of the desired target or the size of the distractor stimuli. There is no process-based definition for Perceptual Load. Are these results on load theory just an indication of manipulation rather than 'Load' itself? Some critics in this field call the correlations made on load theory 'Voodoo Correlations' (Kingstone et al., 2003).

Tsal and Benoni (2010) state that manipulation of the distractors and the perceptual tasks are causally related to the sensory and cognitive factors. The reaction time taken for the desired response is also subjective and depends on the participant's sensory and cognitive limitations. Hence, measuring load solely on the reaction time questions the validity of these studies.

Another major criticism of the manipulation of distractors is the 'dilution' effect. Tsal argues that when the display set for target response is manipulated by changing the number of items in the display, the change in reaction time occurs not due to the presence of distractors alone. Tsal also states that in both the scenarios of high and low display size, the distractors are processed at the same rate, but in the case of high perceptual load or high display size, the reaction time is diluted by the other neutral stimuli present. When Tsal's study controlled the 'Dilution Effects,' it was found that high perceptual load resulted in high distractor interference, refuting the theories so far on Perceptual Load. Thus, it was concluded from the results that the variations in the size of the display set were the reason behind the variations in reaction time, and this, in turn, was due to the dilution effect. This was "misattributed to perceptual load" in past studies (Benoni & Tsal, 2013).

These criticisms suggest that load theory is just one of the indicators of selective attention. Examining other determinants, such as the conditions or the scenarios under which selective attention happens, might be an interesting area to ponder and could be effective in finding an operationalised definition for the load. Bringing subjectivity into attentional research, such as the effect of the modality of the tasks on participants and the difference in designing the task itself, would also aid in understanding the term 'selective' in selective attention better. Another important aspect to incorporate in understanding how selective attention functions in the world is the effect of participant type, i.e., novice and expert participants performing similar tasks. This would unveil the path to determine the performance differences of participants or learners in multiple real-world tasks.

How does attention function in cases of Experts and Novices?

The duration of retaining information or stimuli in Working Memory differs between novices and experts. This retention span essentially equates to an individual's attention span, which is crucial for effective information processing. Novices require a greater amount of attention units to process a specific stimulus compared to experts. This extended retention time consumes a portion of their working memory capacity, as working memory capacity is limited for everyone

(Miller, 1956). However, in the case of experts, the retrieval of complex schemas from long-term memory and their subsequent processing in working memory doesn't significantly deplete their retention time. The attention units necessary for tasks within their domain of expertise demand less retention time. This leaves them with a surplus attention span for processing other incoming stimuli or distractors irrelevant to the assigned task. Experts swiftly determine the relevance of stimuli and identify which parts require a response or processing and which do not. In contrast, novices process stimuli as a whole within their perceptual span. They struggle to pinpoint the relevant components of the stimuli, depleting their attention resources and leaving little to no capacity for retrieval or schema formation.

The information that moves from the working memory to the long-term memory is not stored as isolated facts but as complex interactive procedures or schemas (F. Paas et al., 2010; F. G. W. C. Paas & Merriënboer, 2016; F. Paas & Sweller, 2012; van Merriënboer & Sweller, 2005). A schema categorises fragments of information based on the manner in which they are retrieved by the working memory. Complex schemas are formed effectively and constructively by the combination of similar smaller schemas. The resultant schemas are then stored in an organised manner in the long-term memory. When learning is a prolonged process, the subsequent schema incorporates a huge amount of information. Though there is a limit in the amount of information processed by the working memory, schema construction and automatisation have no limits. Automatisation of schema, i.e., retrieval of information without significant conscious effort, takes place after extensive practice. Schemas are more like sophisticated rules. If a learner possesses a more automated schema, additional space is available in the working memory to solve new complex problems.

Cognitive Load and Problem Solving

A problem in Cognitive Load Theory is a task that requires the individual, i.e. a problem-solver, to engage their cognitive functions to arrive at a desired solution. According to studies on

Cognitive Load Theory (Ashcraft, 1995; Goldstein, 2014; Sweller, 2018) when we develop more expertise in a particular field, the schema relevant to this field becomes exceptionally complex or large. Working memory has a limited capacity in terms of holding chunks of information at a given time. In this scenario, the number of chunks retrieved would still be minimal, but the complexity of the schema retrieved is high, resulting in better problem resolution.

When a complex problem is given to a learner, most tend to work backwards. They move from the goal state to the problem state. The distance between the two is termed the problem space, and if this space is exceedingly large, it results in the overloading of the working memory. This would result in the learner not reaching the desired goal state. Another possibility is that the learner spends too much time decoding the goal state, which would then detract the attention from the information processing or the learning that happens with each problem or task assigned to the learner.

The complexity of the load induced by problems or tasks does not make a learner a better problem solver or an amateur. It is the manner in which a given problem is solved that makes a learner an expert or a novice in a particular field (Chandler & Sweller, 1991; van Merriënboer & Sweller, 2005). The studies on Cognitive Load Theory have classified learners into experts or novices based on three criteria:

Memory of relevant problem-state configurations: This was tested using master chess players and amateurs. It was found that the number of chunks or items of information retrieved from long-term memory into the working memory did not vary in the case of both experts and novices. However, the complexity of the schema retrieved differed substantially in the case of experts. This suggests that the superiority and differences in problem-solving occur not due to the structural differences in working memory.

Problem-solving strategies: Transformational problems or number problems usually consist of a problem or initial state, a goal state, and problem-solving operators. Novices reduce the problem space by using search heuristics or means-ends analysis. The usage of means-ends analysis results in a backward working state, i.e., starting from the goal state and setting subgoals. This continues till the unknown or the desired goal is reached. Experts, on the other hand, eliminate the backward working strategy. Though the problem is new for the expert, they identify the problem state from prior experience and know which equations are required to reach the goal state. They classify problems into different domains of knowledge and select relevant equations or formulas.

Features used in categorising Problems: Domain-specific knowledge in the form of schemas is one of the major factors distinguishing experts from novices. Experts classify problems based on the goal state or the solution state. They understand the deep structure of the problems, while novices go by the surface structure. When this happens, novices fail to notice the problem state or the problem structure. This results in no schema acquisition. When a complex problem is presented to the learners, especially novices, a heavy cognitive load is generated in the working memory. There is a relentless use of the limited working memory capacity because the novice should consider multiple states of the problem in order to solve it – current problem state, goal state, the subgoals set by the problem solver, and identifying the problem-solving operators. This leaves little to no room for schema acquisition.

In cognitive load literature, cognitive load is measured using task performance rate, acquisition time, number of errors, and test performance scores. How much does expertise or subjectivity of mental effort affect the problem-solving strategy? The scales used in empirical studies to rate mental effort or subjectivity were sensitive to the differences in cognitive structure. This is due to the subjectivity of the strategies used by the problem-solvers. The psychophysiological measures used to measure cognitive load were responsive only to significant differences in task complexity. The major challenge in measuring cognitive load is the ambiguity of the quality and quantity of cognitive processes involved in learning and problem-solving.

The major purpose of cognitive load theory is to design an instructional framework that would impose minimal cognitive load and support all learners. Some of the tactics to enhance schema automation are given by Choi et al. (2014). This includes a) Recategorization of problems into domains demanded by the desired goal state; b) Providing worked-out examples to the novices, which includes a step-by-step demonstration of how to solve the problem, applying the relevant formula, and others. This would enhance the initial acquisition of rules and schema construction; c) Understanding the subjectivity in problem-solving and identifying varying learner needs; d) Reduce the problem space between the problem state and the desired goal state. This is mostly achieved by implementing a completion strategy or providing partially solved problems to learners; e) Reducing the 'Goal Specificity' of a problem. This assists in acquiring the necessary cognitive representations of the applicable operators in problem-solving. This can then be replicated when a problem with a similar desired goal state is presented to the learner. The effectiveness of the search strategy could improve with these tactics.

The past decade, studies (H.-H. Choi et al., 2014; F. Paas et al., 2010) in Cognitive Load Theory revolve around the evolutionary nature of human cognitive architecture and its relevance in how problem-solvers approach a novel problem. There is a gap between Cognitive Load Theory and its application in real-world scenarios. Optimising and adapting Cognitive Load Theory in a real-world instructional framework would let us understand the underlying cognitive functions accountable for problem-solving. Accordingly, this research, to understand the cognitive functions of the individual better in an assigned task, has tried to assess the load of the tasks on individuals by incorporating the NASA Load TLX (refer to Chapter 3 for a detailed description) after performing each task on testing modality and selective attention.

Chapter 3.
An Exploration of the Effects of Cross-Modal Tasks on Selective Attention

Abstract: Successful performance of a task relies on selectively attending to the target, while ignoring distractions. Studies on Perceptual Load Theory, conducted involving independent tasks with visual and auditory modalities, have shown that if a task is low-load, distractors and the target are both processed. If the task is high-load, distractions are not processed. The current study expands these findings by considering the effect of cross-modality (target and distractor from separate modalities) and congruency (similarity of target and distractor) on selective attention, using a word- identification task. Parameters were analysed, including response time, accuracy rates, congruency of distractions, and subjective report of load. In contrast to past studies on PLT, the results of the current study show that modality (congruency of the distractors) had a significant effect and load had no effect on selective attention. This study demonstrates that subjective measurement of load is important when studying perceptual load and selective attention.

Introduction

Successful engagement with the environment requires interaction with stimuli presented to the various sensory organs. When performing tasks, we are faced with a continual stream of information in the form of perceptual stimuli. Attention is the mechanism that helps to process various stimuli presented by the different sensory organs. However, attending to stimuli has associated costs, because perceptual processing capacity is an exhaustible resource (Lavie, 2010; Macdonald & Lavie, 2011). One way to deal with this is to attend only to relevant information, e.g., information from the relevant stimuli, i.e., the target, while ignoring distracting information. This is achieved through selective attention allowing for the preferential processing of the presented sensory information relating to features, locations, orientation, and modalities (Posner & Boies, 1971; Treisman, 1969).

A pertinent question in this regard relates to the stage of information processing during which selective attention applies. So-called early-selection theories claim that task-relevant information is selected at an early stage of processing, allowing targets to be perceptually encoded while ignoring distractors (Broadbent, 1966; Cherry, 1953). On the other hand, so-called late-selection theories claim that both the target and distractors are perceptually encoded in the initial stages of processing. It is only at a later post-perceptual stage that target selection for further processing takes place (Deutsch & Deutsch, 1963).

With Perceptual Load Theory, Lavie (1994) brought together these two types of theory. PLT posits that perceptual processing at all times involuntarily processes information to its full capacity. While performing a task, top-down identification of relevant and irrelevant information is led by the voluntary control of perception. Through selective attention, the task-relevant aspects of the stimuli are prioritized for processing. If the task is low load, attending to the target does not engage the whole perceptual process, but as perceptual processing is involuntary and must be used to its full capacity, irrelevant information including distractions is processed along with relevant information relating to the target.

However, if the task is high-load, it consumes all the available processing capacity in attending to the target, leaving no spare capacity for processing the distractions (Lavie, 2010; Lavie & Dalton, 2014). Thus, according to PLT, the stage at which selective attention applies and the allocation of processing capacity depend on the load induced by the task at hand. The load induced by a task is dependent on cognitive demand as well as the perceptual properties of the task (Beck & Lavie, 2005; Cartwright-Finch & Lavie, 2007; Lavie & Dalton, 2014).

Thus, the concept of high or low perceptual load is operationalized on the basis of distractors and targets (Benoni & Tsal, 2013a; Tsal & Benoni, 2010). The task is considered high perceptual load when the distractions or non-target information are not processed. The task is considered low- load when the attentional resources spill over and process distractions along with the target information, a situation known as distractor interference. Corroborating this, results from many studies on PLT have found that the perceptual demand induced by the task determines the allocation of attentional resources. High-perceptual-load tasks preclude processing irrelevant aspects of the stimuli (Lavie et al., 2009; Lavie & Cox, 1997; Macdonald & Lavie, 2011).

Since perceptual load is observable only by the processing (or lack thereof) of distractions, the study and observation of perceptual load can involve manipulations of aspects of tasks, such as the target itself, task-relevant and task-irrelevant distractors, or the objective of the task. Studies involving PLT use these aspects to manipulate and study perceptual load in three different ways. One of these ways is to alter the number of items displayed during perceptual recognition tasks. Increasing the number of items on display increases the complexity of the task, hence increasing the perceptual load. In one of her early studies, Lavie (1995) implemented this method of load manipulation by having the target appear in one out of six possible positions on the visual display, with five positions empty un- der low-load conditions. For high-load conditions, the five positions were occupied by non-target letters. Another method of load manipulation is by keeping the nature and/or number of displayed conditions unchanged while altering the number of operations to be performed to complete the task. Increasing the number of perceptual operations involved in a task increases the task's complexity. In one such study, along with manipulating the load by increasing or decreasing the number of letters in a visual search task, the demands on perceptual judgement were varied by comparison with length discrimination or colour detection using identical stimuli (Cartwright-Finch & Lavie, 2007).

Perceptual load is also affected by increasing the similarity, also called the congruency, between the target and the distractors (Z. Li & Lou, 2019; Pfister et al., 2019; Rosner et al., 2015). Congruent distractors, which have similar properties to the target, compete with the target for attentional resources. Incongruent distractors, which are dissimilar to the target, do not compete with the target (Forster & Lavie, 2008). Studies employing the letter-search paradigm reported that when searching for a target such as the angular letter X, surrounded by congruent distractors like the angular letter Z, the response was faster (shorter response time). If other irrelevant non-target stimuli, e.g., cartoon faces, were also present, these were not even processed (Beck & Lavie, 2005; Lavie, 2005; Lavie & Cox, 1997). However, when searching for the letter X among incongruent distractors such as the circular letter O, the response was slower (longer response time), and irrelevant stimuli were also processed. Thus, for congruent distractors, the perceptual similarity between the targets and the distractions led to higher perceptual load, exhausting the attentional resources. In the case of incongruent distractors, the task was less demanding and perceptual load stated as low, leaving spare attentional capacity to process task-irrelevant information (Lavie & De Fockert, 2003). In short, congruency of distractors and target has a significant effect on selective attention but only when the perceptual load of the task is low.

Issues with PLT

There are two main issues affecting studies reporting the results of PLT, namely the circularity problem and the limiting of experiments to the visual domain. The circularity problem refers to the circular characterization of perceptual load. On one hand, distractor interference is assumed to depend on whether the task is high- or low-load; on the other, whether the task is high- or low-load itself depends on whether or not the distractor causes interference (Benoni & Tsal, 2013a; Tsal & Benoni, 2010). Thus, there is no independent validation of whether a task is high- or low-load. The experimenter testing the effect of load on distractor interference decides a priori whether a task is high- or low-load, and accordingly interprets the performance of participants. To address this issue, in the current study, instead of the researchers assuming the extent of the task load, the participants were asked to subjectively rate the load separately after the experimental tasks.

The second issue with PLT is that the knowledge gained in this context about selective attention and perceptual load is based largely on the visual domain, because studies conducted under PLT have been predominantly in the visual domain. However, our experience of the real world is multimodal in nature, i.e., involving more than one modality. To imitate better the real world scenario of selective attention in studies of perceptual load, it is important to study tasks involving both visual and auditory stimuli (G. Murphy et al., 2016). Because of the evolutionary difference in the functions of vision and hearing in the real world, a difference may also exist in the way an individual interacts with auditory and visual distractions while performing tasks that need attention (Nees & Sampsell, 2021; Spence, 2021; Szychowska & Wiens, 2021).

A small but growing niche of studies have begun to explore the role of auditory modalities in perceptual load, with some reporting unimodal experiments with auditory and visual modalities. These studies found that selective attention is dependent on load, irrespective of the modality. For instance, in a figure–ground segregation study reported by Molloy et al. (2018), task-irrelevant sounds were presented during the performance of a visual search task and the results revealed a 'clear magnetoencephalography neural signature of figure-ground segregation in conditions of low visual load, which was substantially reduced in conditions of high visual load'. Therefore, for both of these modalities, distraction recognition depends on the level of perceptual load. Other studies that conducted unimodal experiments with auditory and visual stimuli included tasks in which the distractions were presented in the same modality as the target (Merz et al., 2021; Molloy et al., 2015; Rees et al., 2001; Roth et al., 2013). Several studies involved tasks using multiple modalities for targets and distractors, but these did not take the congruency factor into consideration (Nees & Sampsell, 2021; Robinson et al., 2018; Spence, 2021; Turoman et al., 2021).

Thus, the research gap in the literature arises from a dearth of studies that (i) involve cross-modal tasks (target from one modality, distractor from another), while (ii) taking into consideration the congruency of the distractors, and (iii) including subjective measurement of load from the participants.

Current Study

Studies of multisensory integration have demonstrated that humans perceive their environment better when they are able to bind perceptual information from different senses and combine this information into a coherent representation. Therefore, in order to study cross-modal perceptual congruency, one must use an object that can be perceived simultaneously by the corresponding senses (Laurienti et al., 2004; Mishra & Gazzaley, 2012). One method employed to achieve this is the use of a picture of an animal (e.g., dog or cat) as the visual stimulus and a corresponding or non-corresponding call (e.g., barking or mewing) as the auditory stimulus (Q. Li et al., 2022). The problem with this is that the buttons for receiving the participant's response need to be labelled with pictures (e.g., of a dog and a cat), which supplies an over-representation of the visual stimulus (i.e., not only as the visual task stimulus but also on the button label) compared with the auditory stimulus (because there is no 'auditory button'). An acceptable solution to this is to label the buttons with words (e.g., DOG and CAT), which requires the participant to read the word on the button. In the current study, we built upon this solution.

In languages with alphabetic writing systems (e.g., English), the textual spelling and phonological pronunciation of a word are integrally connected through orthographic knowledge (Apel, 2011; Apel et al., 2019). For unknown and less familiar words, the speaker of a language would read the words piecemeal, but for common and familiar words, the spelling and pronunciation are stored together as a picture–sound unit in the individual's lexical orthographic knowledge, such that the sight of a printed or written word invokes its pronunciation, and vice-versa. Thus, words contained in the individual's lexical orthographic knowledge, i.e., very frequent and highly familiar words, undergo cross-modal (visual and auditory) activation. Correspondingly, we assume that the task of reading one word while listening to a different word would represent a cross-modal target–distractor paradigm. With this in mind, we used frequently occurring Indian English words and their corresponding utterances as cross-modal stimuli in the current study. The task was perceptual in nature because it involved integration of two perceptual modalities in the form of targets and distractors. This also allowed the buttons to be labelled with single letters (initial letters of the names of the stimuli) which helped to avoid over-representation of the visual or auditory stimuli. Within this paradigm, because of the use of meaningful words, the semantic congruency was cognitive in nature.

We employed the aforementioned model in the current study design to address the previously mentioned research gap by: (i) incorporating cross-modality in choosing the targets and distractors, i.e., for a visual target, then the distractor was auditory (and vice versa), (ii) using two different types of distractors, i.e., congruent and incongruent, and (iii) asking the participants themselves to rate the load of the tasks after completion. The overarching research objective was to see if congruency and modality of distractors (vis-à-vis the target) affected the perceptual load of tasks.

On the basis of results from previous studies involving PLT, in the present study it was expected that modality would not play a significant role in selective attention; thus:

Expectation 1: There would be no significant differences in the response times and accuracy scores of the participants for tasks from any modality.

Furthermore, results from PLT studies also showed that congruency of distractions has no significant effect on the performance of participants, thus:

Expectation 2: There would be no significant difference in the performance scores of participants for tasks with varying distractor congruency.

If the performance scores of participants in bimodal audio–visual tasks do not fluctuate, we can conclude that the results align with the existing research and study results relating to PLT. Such a result would indicate that selective attention functions in a uniform way irrespective of modality, and that the congruency of distractors on target recognition in a task is load-dependent in its effect rather than modality-dependent. If the results do show differences, it could indicate that selective attention varies with the nature and modality of the task. This would imply that apart from load being induced by the task itself, i.e., some tasks being inherently difficult or easy and thereby classified as high- or low-load tasks, the inclusion of targets and distractors from two different modalities affected selective attention, leading to slower reaction times and lower accuracy scores.

The current research incorporated a post-experiment questionnaire to measure the load of the auditory and visual tasks included in the study. This provided a subjective measurement of load as indicated by the participants. The participants were asked to recall the task they completed involving a particular modality and to rate the task using the parameters stated in the questionnaire. Consequently, two sets of the questionnaire were distributed in order of completion of the experiments. The scores given by the participants were assessed by the experimenters to discover whether the reaction times and accuracy scores across the two tasks with different modalities were indeed affected by the task loads. This post-hoc measurement is considered important to provide an unbiased interpretation of load, which could not be achieved if the load were predetermined by the experimenters. It is important to note that this post-experiment questionnaire provided results that were indicative of the cognitive load or the working memory load, because it involved participants' recall (Lavie, 2010).

Materials and Method

Participants

Thirty-one participants (14 females; mean age = 30 years), with reported normal hearing and vision, were recruited from BITS Pilani's Hyderabad campus. The participants received rewards of stationery for their participation. Each participant took part in the two experimental tasks on the same day. The participants provided informed consent before their participation.

Apparatus and Stimuli

Audacity® (version 3.0.0) was employed to record and process the auditory inputs. These inputs were then utilized for construction of the experiment in PsychoPy Experiment Builder version 3.0. The open-source version of RStudio, the integrated development environment (IDE) for R, was employed to analyse the data. RStudio used the statistical tool R (64-bit, version 3.5.1) for the analysis. All the packages that were applied in R were installed through the R-Cran cloud library. For plotting the graphs generated by R, Rcmdr package version 2.5-1 was used. The auditory inputs were delivered using Audio-Technica ATH-M20x over-the-ear headphones. The NASA task load index (TLX) Version 1.0 paper and pencil package was used for subjective task-load ratings (Gore & Kim, 2019).

Three words for colours, namely *Red*, *Green*, and *Blue*, and three non-colour words, namely *Pen*, *Lid* and *Mug* were recorded spoken by a female voice in a sound-treated chamber. The words were monosyllabic, commonplace English terms, 500 ms in duration, and normalized in intensity with each other.

Procedure

For experiments 1 and 2, the participants were seated in a sound-treated chamber and presented with visual stimuli on a computer screen and auditory stimuli through headphones. They recorded their responses with mouse clicks. Each of the experiments comprised a training session followed by two experimental tasks. On-screen and verbal instructions from the experimenters were provided to the participants during the training, and before (but not during) each task. The participants kept the headphones on during the training and the tasks.

The experiment commenced with training in which the participant was familiarized with the user interface, the stimuli, and the process. During the training, participants were permitted to adjust the volume of the audio and the brightness of the screen to meet their preference. These settings then remained unchanged for that participant for both experimental tasks. The training was repeated until a participant was confident and had no more questions.

In order to reduce any strategy-based effects of modality on the performance of participants, and to compensate for any potential bias, half of the participants performed the visual task first, followed by the auditory task. The other half completed the auditory task first, followed by the visual task.

Experiment 1: Visual Task (VT)

The effect of selective attention on visual modality was tested using the visual task. In VT, the target of the task was the visual stimulus, and the distractor was the auditory stimulus. Refer to Figure 1 for a representation of a typical trial. Before the task and during the training, the participants were asked to ignore any auditory stimuli they might hear during the task. For the first 500 ms of each trial, participants were presented with a '+' fixation symbol on the screen, along with an alerting auditory tone delivered through the head- phones. Soon after the fixation and the alert tone, the visual target and auditory distractor were presented simultaneously on the screen and through the headphones, respectively.

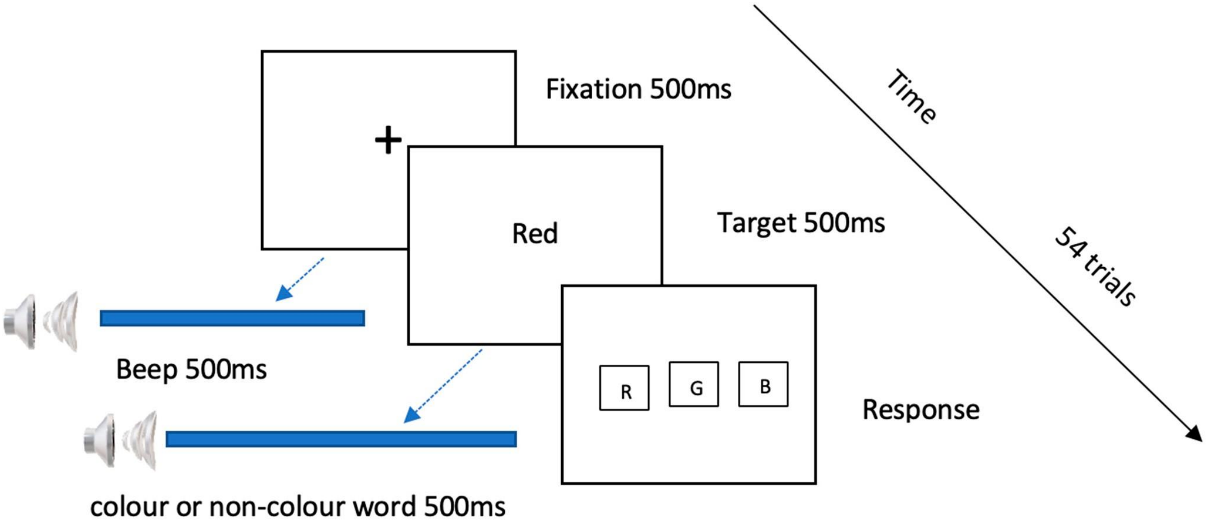

Figure 1:Schematic representation of a trial in the visual task (VT). The visual fixation '+' was presented with a simultaneous auditory fixation beep. The target presented on the screen was a colour word. The distractor, simultaneously presented auditorily, was either a colour or a non-colour word displayed on the screen. The response was recorded via on-screen buttons

The visual target was a randomly selected word from the pool of only the colour words. This word was displayed on the screen for 500 ms, in black Times New Roman font. The auditory distractor was an auditory stimulus randomly selected from the pool of colour and non-colour words. The visually presented word in the VT was always a colour word, therefore a colour word as an auditory stimulus was a congruent distractor, while a non-colour word as an auditory stimulus was an incongruent distractor.

After the presentation of the target and distractor, three on-screen buttons appeared with the text 'R' for red, 'B' for blue, and 'G' for green. The task was to identify the colour word presented visually on the screen, by clicking the corresponding on-screen button using the mouse. Immediately after the response from the participant was received through the mouse click on any of the three on-screen buttons, the next trial was presented automatically. There were 18 unique pairs of target visual stimuli (3 colour words) and distractor auditory stimuli (6 colour or non-colour words). Each pair was presented three times, making a total of 54 trials for the VT.

Experiment 2: Auditory Task (AT)

The auditory task (AT) was similar, but with an auditory target of colour words, and distractors of either a colour or a non-colour word presented on the screen. The effect of selective attention on the auditory modality was tested with target stimuli from the auditory domain and distractor stimuli from the visual domain. During the training for the task and again before the actual task began, participants were asked to attend to the auditory stimuli while ignoring any visual stimuli on the screen. The set-up and number of trials were similar to VT as described earlier, except that for each trial a randomly selected colour word was presented through the headphones as the auditory target stimulus, while a randomly selected visual stimulus from the pool of colour words (congruent distractor) and non-colour words (incongruent distractor) were presented on the screen.

The task was to identify the colour word presented as the auditory stimulus through the headphones, by clicking the corresponding on-screen button using the mouse.

Post-Test: Task-Load Questionnaire

For measuring the subjective perception of load for visual and auditory tasks, the NASA load TLX questionnaire was distributed to the participants, each receiving one questionnaire after each task. The questionnaire asked the participants to rate the task subjectively on a set of six scales (Mental, Physical, and Temporal Demand; Effort, Frustration, and Performance) on a rating sheet. Each scale was presented as a line divided into 20 equal intervals. The participants marked their responses using tick marks on the given rating scales. Ratings were obtained after each task was completed. Computerised analysis (from NASA Ames Research Centre) was employed to calculate the magnitude of load according to the participant ratings (Gore & Kim, 2019).

Measures

Within each task, a trial was considered to be correctly attempted if the participant clicked the button corresponding to the colour word presented as the target (visual in VT, and auditory in AT); otherwise, the trial was deemed incorrectly attempted. Each trial was considered a data point; a score was assigned for each correctly attempted trial, while an incorrect attempt received no score. Total numbers of correct attempts were used for statistical analysis.

For each trial, the response time (RT) in milliseconds was calculated as the time taken from the presentation of the on-screen buttons to the event of the mouse click on one of the buttons. Load scores from NASA load TLX indicated the task load.

Catch Condition

In Experiment 1 (VT), where the auditory distractors supplied to the ear were congruent and incongruent in nature, the gender of the audio inputs were changed exactly 3 times. This change in gender of the audio inputs while performing the visual task was the catch condition.

In Experiment 2 (AT) the visual distractors, both congruent and incongruent, were displayed on the screen. In this case the catch condition was a change in font size from the existing stimuli size to almost double to that of the visual inputs. The change in font size of the visual inputs happened exactly 3 times.

The catch conditions in both the experiments were presented at regular intervals, ensuring that the participant did not encounter the catch condition in back-to-back trials. If the perceptual load of any of the tasks was deemed to be high, it was assumed that the congruent and incongruent distractors and the catch conditions would not be processed.

Results

The G*Power test was conducted to find the power ($1 - \beta$ err prob) using an F test—ANOVA: repeated measures within-between interaction. This post hoc analysis was carried out to compute achieved power. The effect size (f) was 0.25 and the α error probability was set at

0.05. The power achieved was (1 − β err prob) = 0.913.

Across the two tasks, we were interested in the effect of modality on perceptual load, and the effect of congruency of the distractor with the target. To this end, the mean accuracy scores and mean RTs were calculated as a function of the effect of congruency of the distractors and type of modality on the performance of the participants.

Accuracy

The plot of mean accuracy scores for AT and VT is shown in Figure 2. The accuracy scores were lower for VT with congruent distractors ($M = 0.92$, $SD = 0.25$) compared with incongruent distractors ($M = 0.93$, $SD = 0.24$). AT had better accuracy scores for congruent and incongruent distractors, compared with VT (congruent $M = 0.99$, $SD = 0.05$; incongruent $M = 1.00$, $SD = 0.00$). Furthermore, 2 × 2 ANOVA was conducted to examine the effect of the type of modality (i.e., AT vs. VT) on accuracy scores. The result showed that the modality had a significant effect, $F = 111.56$; $p < 0.001$. The congruency type did not have a significant effect on the type of modality ($F = 0.92$, $p = 0.33$).

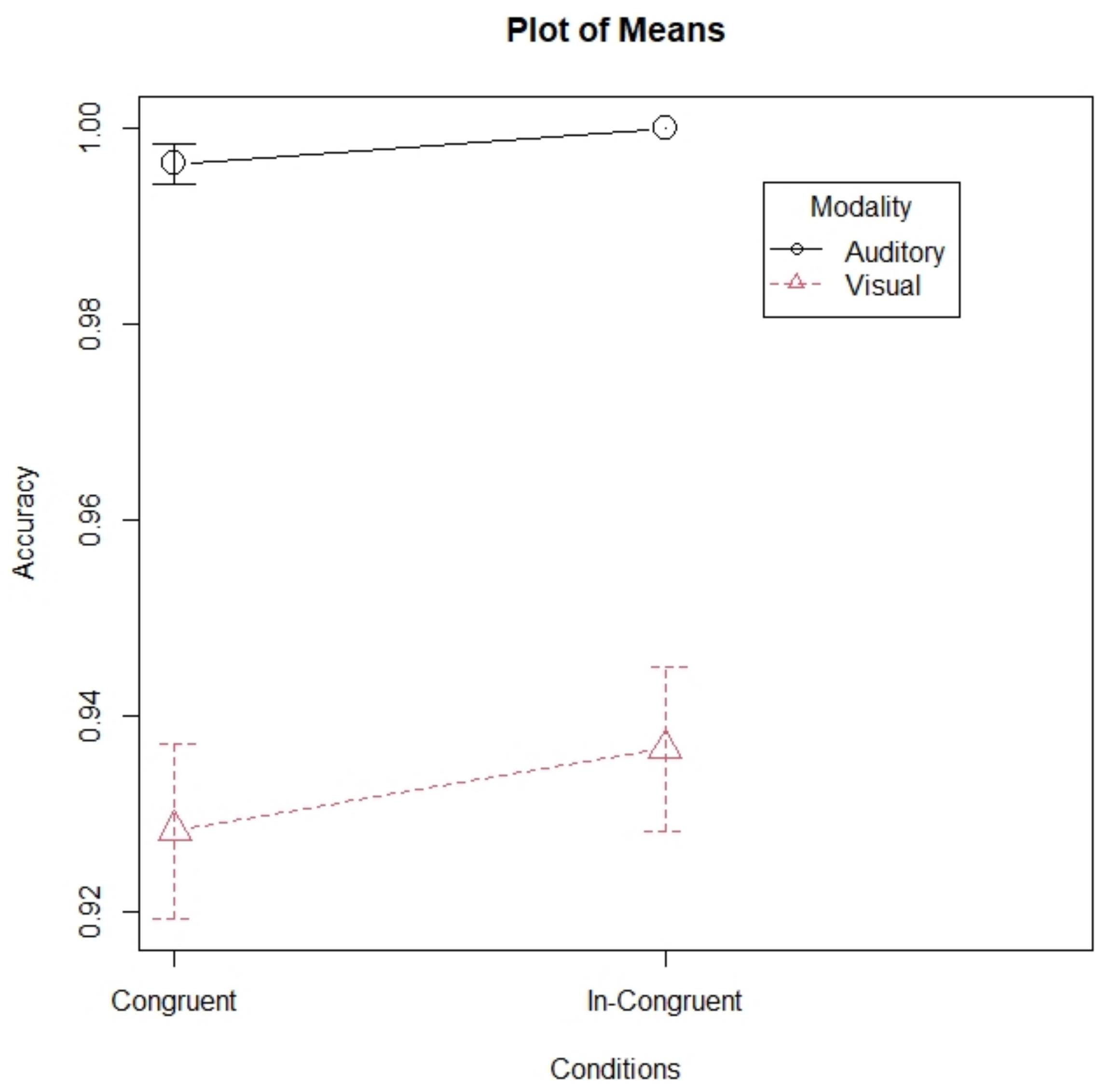

Figure 2: Plot of mean accuracy scores for visual and auditory tasks. Note that the Y-axis does not begin at zero.

Response Time

The plot of mean response-time scores for AT and VT is shown in Figure 3. The 2 × 2 logRT ANOVA for type of modality on response time showed a significant effect, $F = 17.26$, $p < 0.001$; refer to Figure 4 for the distribution of RT data points. The RTs for VT with incongruent distractors were longer ($M = 0.99$, $SD = 2.2$) compared with congruent distractors ($M = 0.72$, $SD = 0. 45$).

AT in general required shorter RTs (congruent M = 0.69, SD = 0.36; incongruent M = 0.69, SD = 0.35) compared with VT. Variable congruency type had a significant effect on type of modality of tasks ($F = 11.19$, $p < 0.001$); refer to Table 1 for the ANOVA results.

Figure 5 reports the results from the post hoc test for the type of task modality (AT and VT) and the congruency of distractors. There was a significant interaction between incongruent auditory distractors and VT.

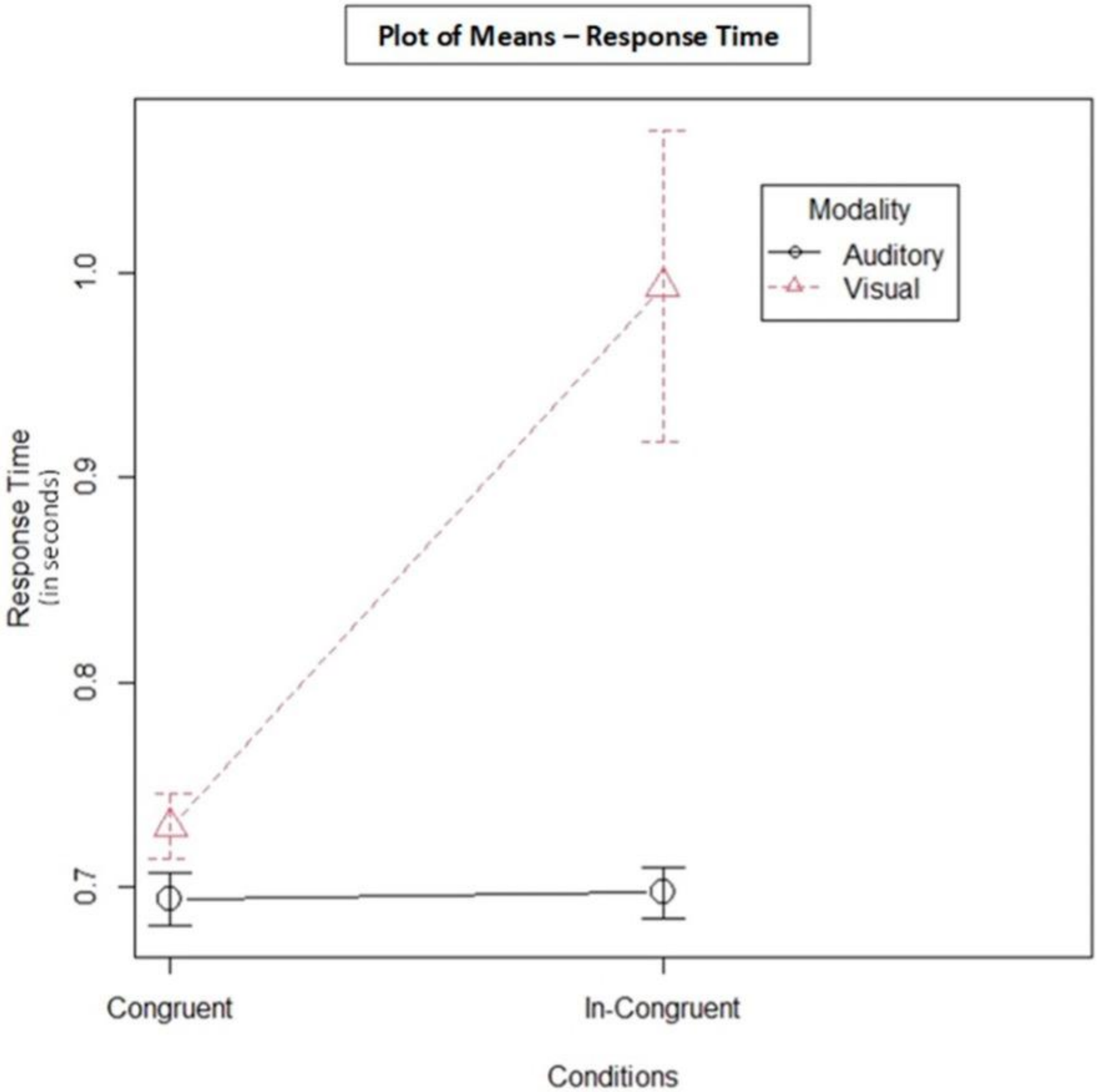

Figure 3: Mean response times for auditory and visual tasks. Note that the Y-axis does not begin at zero.

Load

The NASA load TLX was employed to calculate separately the perceived load scores for both visual and auditory tasks. Mean load scores for the types of modalities are shown in Figure 6. For the participants who completed VT first, the mean visual load was 43.60, and the mean auditory load was 33.17. For the participants who undertook AT first, the mean auditory load was 36.03, and the mean visual load was 46.69. This shows that irrespective of the order in which the tasks were performed, the mean load of VT was consistently higher than that of AT. Consequently, while the mean load for AT remained the same irrespective of the order in which the tasks were performed, the mean load for VT increased substantially when VT followed AT. The MANOVA results for mean load scores and the order in which participants completed the tasks showed no significant effect of task order on the subjective load scores ($F = 2$, $p = 0.937$).

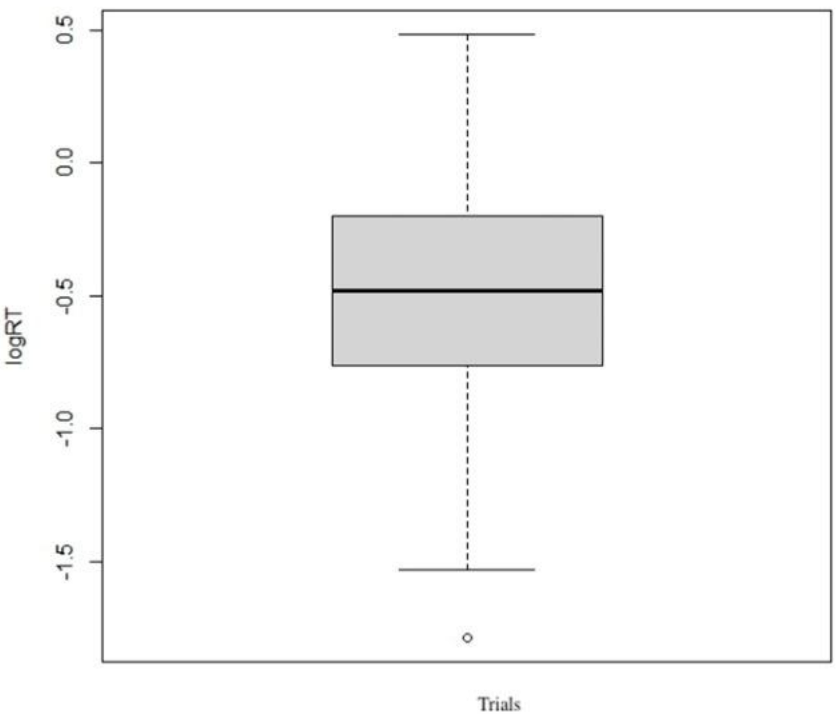

Figure 4: Box plot showing the distribution of response times in seconds from all participants.

*Table 1: Two-way analyses of variance for accuracy and response times in auditory and visual tasks. Significance codes: 0 '***' 0.001 '**' 0.01.*

Measures	**Sum Sq**	**F**	**Pr (>F)**
Accuracy			
Congruency	0.030	0.9220	0.3370
Modality	3.614	111.5601	<2 × 10−16 ***
Congruency × Modality	0.005	0.1475	0.7009
Response Time			
Congruency	14.9	11.194	0.0008298 ***
Modality	22.9	17.262	0.00003337 ***
Congruency × Modality	14.2	10.710	0.0010762 **

Pearson's correlation coefficient test was conducted to determine whether any correlation existed between load and RT, or between load and accuracy across modalities. The results show that for AT, there was no correlation between load and RT ($r = 0.122$, $t = 0.50$, $p = 0.618$) or load and accuracy ($r = -0.19$, $t = -0.82$, $p = 0.42$). However, there was a positive medium correlation for VT between load and RT ($r = 0.42$, $t = 1.926$, $p = 0.071$), and a negative medium correlation between load and accuracy ($r = -0.311$, $t = -1.34$, $p = 0.19$). For the catch conditions across both experiments, a paired t-test was conducted. For the

AT, /t/ = 3.5, there was a significant difference between participants observing (no. of catch conditions = ≤3) and not observing the catch conditions (no. of catch conditions = 0). For the VT, /t/ = 1.75, there was no significant difference between participants observing (no. of catch conditions = ≤3) and not observing the catch conditions (no. of catch conditions = 0). Refer to

Figure 7 for a summary of catch conditions for each task.

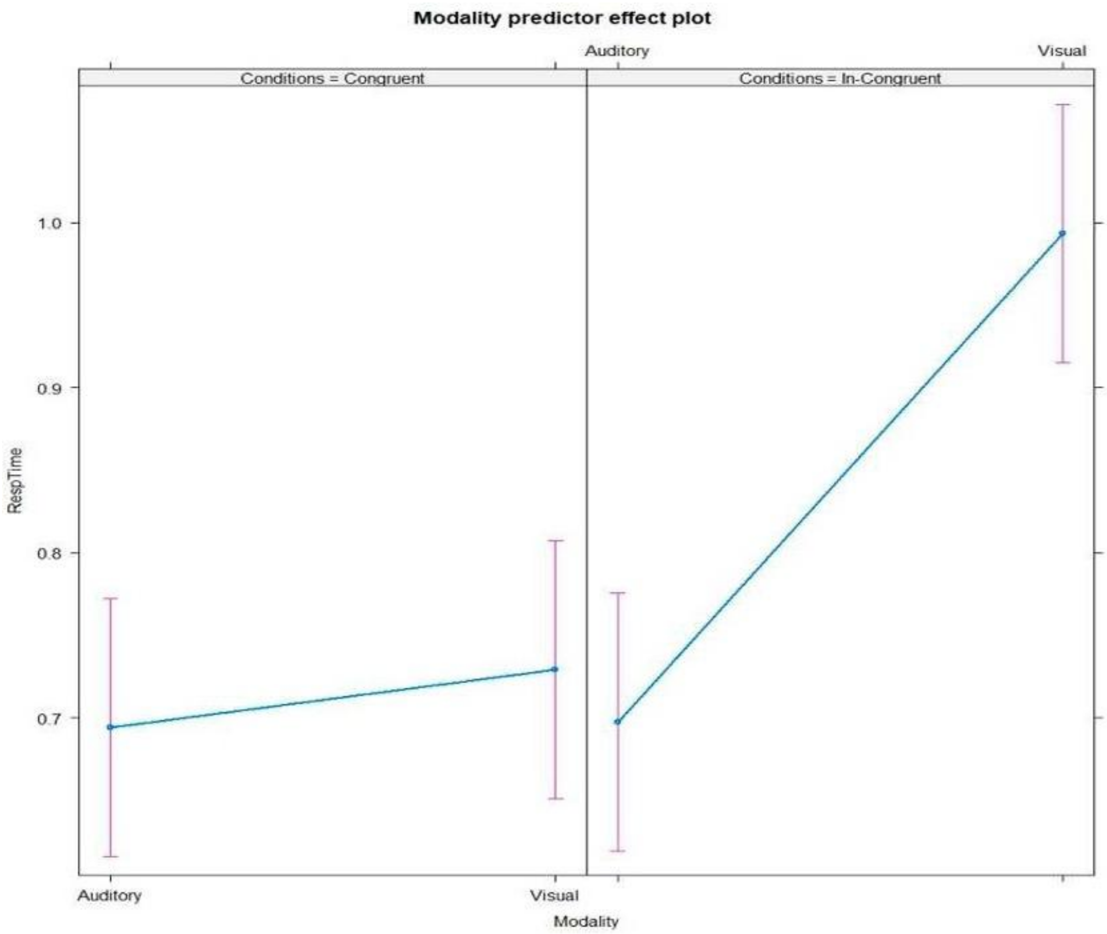

Figure 5: Plot of post hoc modality predictor effect for interaction between condition (congruent and incongruent distractors) and modality (auditory or visual) of the tasks.

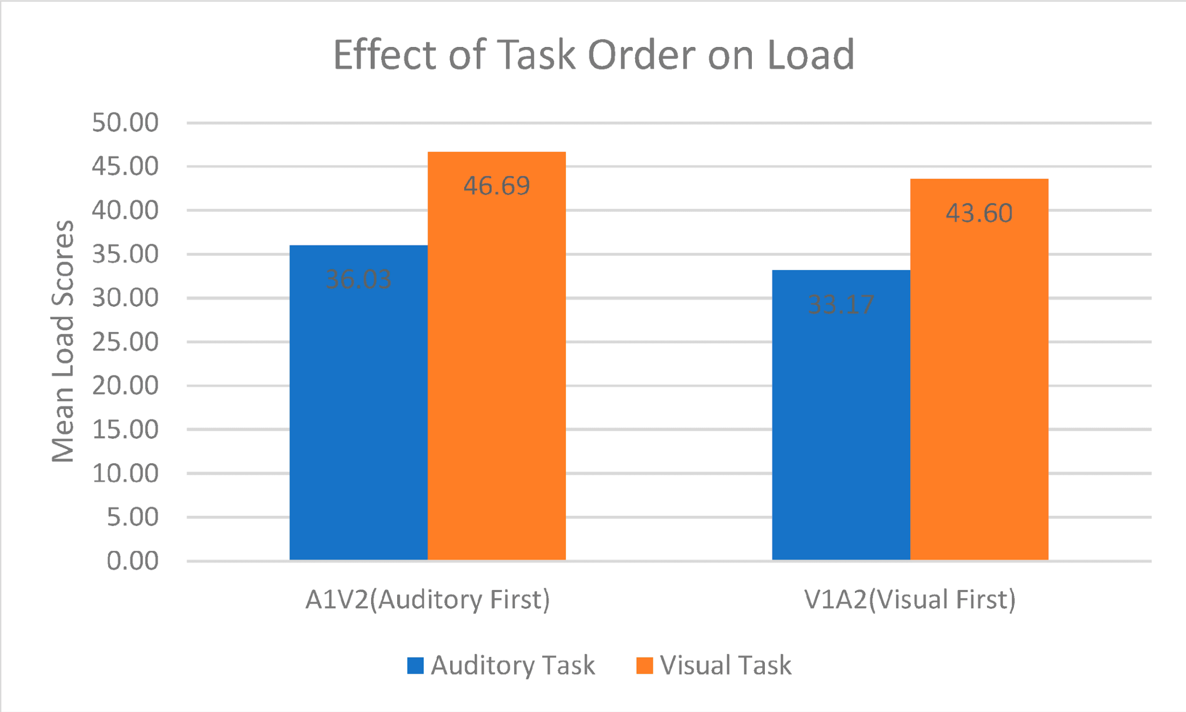

Figure 6: Mean load scores according to type of modality.

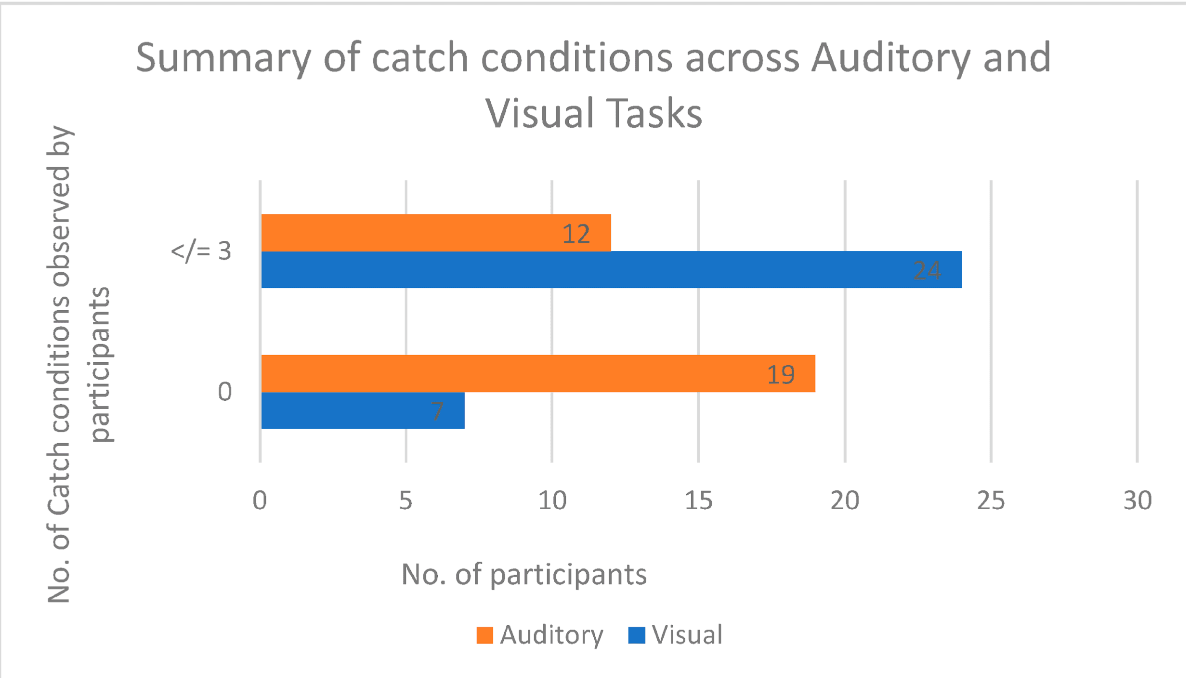

Figure 7: Summary of catch conditions across auditory and visual tasks.

Discussion

The objective of the current study was to determine whether the congruency and modality of distractors affect perceptual load of tasks. The results indicate that there is indeed had an effect of on the response times and accuracy scores of the participants.

Most of the earlier multimodal studies on attention included targets and congruent distractions of the same modality, with incongruent distractions of a different modality (Forster & Lavie, 2008; McEvoy et al., 2007; Molloy et al., 2015, 2018). These studies showed that congruent distractions interfered with targets more than incongruent distractions. When the semanticity of the distractors was the determinant of the congruency, compared with incongruent distractors (with less semantic similarity to the target), congruent distractors (with greater semantic similarity) were shown to have a greater interference effect on the performance of participants. Our first finding was based on analysing the effect of modality, using congruent and incongruent distractors with a different modality than the target. We alternated between the target and the distractors by switching the modalities from auditory to visual and vice versa. The results show that the auditory distractors interfered more while subjects were performing VT, whereas the visual distractors did not interfere so greatly with AT. The accuracy scores were higher for AT with visual distractions compared with VT with auditory distractors. This finding indicates that modality plays an important role when selectively attending to a particular target. The results explain why certain everyday visual tasks such as driving, where accidents might be caused due to listening to phone conversations, are more prone to interference from auditory distractions. The present study indicates that auditory distractors, especially distractors incongruent to the target, cause higher levels of interference while performing VT.

Our second finding was based on the effect of distractors on the target. While performing a task, studies show that distractors congruent to the target caused more interference compared with incongruent distractors. Previous studies (Beck & Lavie, 2005; Forster & Lavie, 2021;

Lavie & Cox, 1997; Pfister et al., 2019) of distractor interference had used responses provoked by congruent or incongruent distractor stimuli alongside the target. The present study eliminated this response–competition paradigm involving the distractors, as the participants were not required to respond to distractors while performing the task. Previous studies of the effects of congruency have generally used only a single modality, i.e., targets and distractors both of the same modality. The present study employed targets and distractors of different modalities, with different congruency ranges, in effect better mimicking a real-world scenario. The results indicate that incongruent auditory distractors were more distracting, with the RT for VT much longer compared with AT. On the contrary, the RT for congruent distractors in both modalities remained almost the same. Our post hoc results also confirm this (Figure 5). This shows that distractors incongruent to the target, irrespective of their modality, interfered with participants' selective attention and had an effect on their performance.

It should be noted that the congruency between targets and distractors in both AT and VT in our study can be classified as semantic congruency. Previous studies on cross-modal semantic congruency show that multisensory stimuli affect attentional control (Q. Li et al., 2022; Yu et al., 2022). Our results showed that incongruent distractors were more distracting than congruent distractors, and congruent distractors had no effect on target selection. The latter may be due to the reallocation of attentional resources to the target stimuli facilitating the performance of participants, as we included cross-modal semantic congruency in our tasks (Mastroberardino et al., 2015). A previous study found that attentional load did not affect the integration of audio–visual stimuli which were semantically congruent to the target, but also revealed potential suppression of the alertness effects induced by incongruent stimuli (Yu et al., 2022). We also observed no effect of semantically congruent distractors on RT for AT or VT when there was a shift in attentional load within the tasks. The load of the tasks did not suppress the effect of incongruent stimuli on selective attention. Irrespective of cross-modality, the incongruent semantic distractors were more distracting during the tasks. The extent of interference from incongruent distractors reflected in slower RTs and lower accuracy rates might be dependent on the high working memory load or high cognitive load. High cognitive load induced by the incongruent condition results in greater interference from incongruent distractors.

Our third result relating to the load induced by tasks its effect on distractors stands in contrast to the findings of previous research in the field of PLT (Macdonald & Lavie, 2011; Molloy et al., 2015). PLT suggests that higher load is accompanied by lower distractor interference, and lower load allows higher distractor interference. In the present study, the subjective load measured using the NASA TLX questionnaire indicated higher load scores for VT compared with AT. Participants reported higher load for VT when it was performed after AT. According to previous studies, this should have eliminated the interference effect of congruent as well as incongruent auditory distractors on VT. However, the Pearson's correlation results for VT load showed a medium positive correlation with RT and a medium negative correlation with accuracy. This indicates that in the high-load task (VT), the RT of the participants increased and there was a drop in accuracy rates. Although VT was marked as a high-load task, it was more affected than AT by distractors. In VT, 24 participants reported noticing the catch condition, compared with only 12 participants noticing it in AT. According to previous studies in PLT (Molloy et al., 2015, 2018), AT should have shown higher distractor interference, as the participants in our study reported it to be a low-load task.

The Pearson correlation results showed no significant effect of load on RT or accuracy for AT. Contrary to previous findings (Lavie et al., 2014; Molloy et al., 2018; Nagle & Lavie, 2020, 2020; Stolte et al., 2014), which suggest that high-load tasks improved performance by effectively blocking distractions, the present study showed comparatively low performance in the high-load VT compared with the low-load AT. Modality, therefore, should be considered a significant parameter when designing tasks in PLT studies.

Conclusion

The present study establishes that congruency of distractors and targets affects selective attention and the perceptual load of tasks. It also seems that auditory distractors in visual tasks cause more subjective load than visual distractors in auditory task. Previous studies in PLT have indicated that if the load of a task is particularly high, neither the modality nor congruency of distractors should affect the performance of participants. Contrary to that notion, our results indicate that even when the load is high, congruency affects selective attention. Our results suggest that the effects of modality should be considered when designing tasks for the study of selective attention. These results emphasise that modality is as influential as load in terms of its effects on selective attention. In future, further studies should be performed with a larger pool of participants from varying backgrounds to determine the effects of other parameters including culture, gender, and socio-economic strata, to obtain richer results.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Ethics Committee of Birla Institute of Technology and Science, Pilani, Hyderabad Campus, India (Protocol Code—BITS-HYD/IHEC/2022/04).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data are available at: https://osf.io/3xu52/?view_only=fdd6a1e5178b40dbb0feb3b0cff7f612.

Chapter 4.
The effect of script reform on levels of orthographic knowledge: Evidence from alphasyllabary Malayalam scripts

Abstract: This study explores the idea of the two levels of orthographic knowledge, i.e. lexical and sublexical; in particular, how these levels are affected in the case of the Indian language Malayalam that went through a script reform in 1971. Through reading and writing tasks, we compare the performance of elderly participants who gained literacy in the traditional script (with complex ligatures), with younger participants who gained literacy in the reformed script (with simpler glyphs). Both the groups read text faster in reformed script indicating script simplification was beneficial. While writing, the elderly participants largely employed the traditional script and younger ones used the reformed script. The study provides proof from non-European alphabet that orthographic knowledge indeed has two independent but related levels. Although a change in script affects both the levels, sublexical one seems more resistant to change, possibly due to less opportunities to update it.

Introduction

Orthography, which literally means 'correct writing', deals with written forms of languages, including writing systems, script, and spelling and punctuation conventions. Primarily, it deals with the conventions mapping the spoken language with its script, which is the set of visual symbols employed to graphemically encode the spoken language (Padakannaya et al., 2022). As a field of study, it enjoys a unique position because it combines insights from such myriad fields of research as linguistics, typology, psychology, and reading-writing (Pae, 2020; Pae & Wang, 2022). From a social and policy perspective, orthography is important because it is the most indispensable component of literacy acquisition (Apel et al., 2019). Despite its important influence on a number of fields of inquiries, orthography has faced some challenges. For example, there has been a lack of consistence in defining and measuring concepts in orthography (Apel, 2011; Apel et al., 2019). Apart from this, a significant number of studies are Anglo-centric or Euro-centric, conducted on limited scripts and spelling systems, leading to a noted lack of diversity in the data in the field (Nag & Snowling, 2012; Share, 2008). For example, see Vaid and Padakannaya (2004) for an overview of different results from alphasyllabaries compared to alphabetic script. There is a lack of data from people who are biliterate and biscriptal (i.e. have the ability to read and write two scripts) from non-Euro-centric languages with the shared mental lexicon of two different orthographies which are not alphabetic in nature (Vaid, 2022a).

This underscores the importance of conducting studies on orthography, but with other languages, scripts and writing systems, and correlating the results to see if the existing theories and frameworks continue to hold. This study, based on reading and writing of Malayalam script, tries to address the aforementioned issues, while referring to the concept of orthographic knowledge. We chose Malayalam not only because it is one of the little studied scripts from the Indian subcontinent, but also because spurred by the change in script few decades ago, it provides a unique opportunity to do a comparative analysis of two generations of Malayalam readers, each primarily literate in a different version of the Malayalam script. Given the old age of the users of the older script, this study capitalises on a fast-closing window.

Malayalam orthography

Evolution of Malayalam script

Malayalam is a language with almost 38 million speakers, spoken primarily in the state of Kerala in India (*Official Website of Kerala.Gov.In*, 2007; *Official Website of Kerala.Gov.In*, 2009; Wikipedia, 2022). Malayalam orthography traces its roots to the ancient Brahmi script, making it an alphasyllabary system. However, because of its own rich history and influence from neighbourhood linguistic communities, Malayalam script has undergone several changes and accumulated writing conventions from different eras and communities. Over a span of a few centuries, it was written with various variants of Brahmi, e.g., Vatteluttu (northern script), Grantha (scripture script), Koleluttu (rod script), Malayanma, and Aryaeluttu (elite script), etc. (Department of Archaeology, 2010; Mundkur, 2020; The Editors of Encyclopaedia Britannica, 1998). As a result, by the middle of the 20th century, its orthography had become extremely diverse and complex. It not only had compound ligatures but also different writing versions for the same graphemes influenced by the different prevailing styles. By the 1950s, the prevailing Malayalam script had more than 1200 graphemes in the form of complex glyphs and ligatures, with sometimes more than one style of forming graphemes for the same clusters of consonants and/or vowels (Manohar & Thottingal, 2019).

In 1958, the state government of Kerala passed the Kerala Education Act, incorporating free and compulsory primary education within the state. A planned implementation of this allowed Kerala to become the first state in India to achieve nearly 100% literacy by the 1990s (Government of Kerala, 1971; Manohar & Thottingal, 2018). As both the cause and effect of the improved literacy, Kerala experienced an ever-increasing demand for books, periodicals, pamphlets, and other printed material. Incorporating all the diverse ligatures of the Malayalam script in print and publications became a major challenge for the publication houses. At this time, the arrival of indigenously built, hence affordable, Indic script typewriters paved the way for distributed, faster, and longer-lasting record keeping, thus boosting the print media circulation in other native languages (Chandna, 2019). However, the development of the Malayalam typewriter faced the challenge of organising its inventory of often redundant complex graphemes in the limited space of typical manual typewriters. A solution to this would have helped the large-scale offset printing as well.

Orthography Reform in Malayalam

In 1971, the Kerala government acknowledged 'the unwieldy number of alphabets and signs in Malayalam' and the consequent labour involved in the process of printing (Government of Kerala, 1971). A government committee found that by writing the consonants and diacritics separately rather than as complex ligatures the number of graphemes in Malayalam could be reduced by 75%, thus suggesting, (i) to discard the usage of complex conjuncts, (ii) and to detach the vowel notations from the consonants and conjuncts. Consequently, the state of Kerala passed the order, 'Malayalam Script—Adoption of New Script for Use', in 1971 to discard the usage of ligatures to represent complex conjuncts, and to simplify them (Government of Kerala, 1971; Kerala State Literacy Mission Authority, 2019, 2022; Mundkur, 2020; UNGEGN Working Group on Romanization Systems, 2016). Through this order, a newer script called 'പുതിയ ലിപി' (read: puthiya lipi, meaning reformed script) of Malayalam came into effect on 15 April 1971. Henceforth, the older script shall be referred to as the traditional script (TS) and the newer version as the reformed script (RS). The 1971 order (Figures 8 and 9) brought down the number of graphemes from 1200 to a standardised 90, that includes 18 vowels and 39 consonants. This script reform initiated by the government was a major event in the evolution of the Malayalam orthography.

GOVERNMENT OF KERALA
Abstract

MALAYALAM SCRIPT-ADOPTION OF NEW SCRIPT FOR USE-ORDERS ISSUED

EDUCATION 'P' DEPARTMENT

G. O. (P) 37/71/Edn. Dated, Trivandrum, 23rd March 1971.

Read: G.O. (P) 329/68/Edn.dated 11-7-1968

ORDER

The question of reducing the unwieldy number of alphabets and signs in Malayalam which consume much time and labour in the process of printing and typewriting, has been under consideration of Government for some time. In 1967 Government appointed a Committee with Shri Soornad P. N. Kunjan pillai, Editor, Malayalam Lexicon as convener to advise them on the question of reformation of Malayalam script. The committee in its report has made recommendations to reduce 75% of the total number of existing characters in printing and typewriting. The reformed Malayalam script recommended by the above Committee was revised with slight modifications by another committee appointed in 1969 to expedite the adoption of the new script for use. The recommendations of the above two committees in the matter of reformation of the Malayalam script are in brief as follows:

i. ഉ, ഊ, ഋ, റ എന്നിവയുടെ മാത്രകൾ വ്യഞ്ജനങ്ങളിൽ നിന്നും വിടുവിക്കുക

ii. പ്രചാരം കുറഞ്ഞ കൂട്ടക്ഷരങ്ങൾ ചന്ദ്രക്കല ഉപയോഗിച്ച് പിരിച്ച് എഴുതുക.

2. In January 1971 a conference of Managing Editors of important newspapers in the State was convened to discuss the question of adoption of the new Malayalam script for use. The conference has recommended that the reformed script as revised by the committee might be adopted for use with effect from 15th April 1971 (Vishu Day).

3. Government have considered the question in detail and are pleased to accept the reformed Malayalam script as revised by the Committee for use. The new script will be adopted for all official purposes with effect from 15th April 1971 (Vishu Day). A booklet "ലിപിപരിഷ്കരണം" containing the details of the new script accepted by Government is appended to this G.O.

4. All newspapers and periodicals in Malayalam are requested to co-operate with Government in the implementation of the scheme and to adopt the new script from the stipulated date.

Figure 8: Reform order snapshot: A short table describing the major proposals by the Kerala government in 1971 reform order, and some examples of the resulting differences in the traditional and reformed script.

Orthographic knowledge and age

Orthographic knowledge is the interpretation of spoken language in print (Apel et al., 2019). The specific graphemic form of any writing system includes the letter shape, letter/grapheme configuration (Roman letters vs. Devanagari), syllable (or character) formation, diacritics or circumflexes, word constituents (simple or compound words), spatial relations, and syllabic format. These constituents yield considerable effects on the mental processes of individuals, such as their thinking, reasoning, stimuli recognition, concept formation and worldview (Padakannaya et al., 2022; Pae & Wang, 2022). There is a relation, therefore, between other constituents of language, mental processes associated with language processing and its orthographic form or the script. The mental orthographic knowledge is a reflection of the external linguistic system of a language.

No.	***Proposals in 1971 Kerala Govt. Order***	***Traditional Orthography (TS)***	***Reformed Orthography (RS)***
1	Detach the signs of vowels ഉ(u), ഊ(u:) and ഋ(rɨ) from the base grapheme.	i.കു (ku) ii.കൂ (ku:) iii.കൃ (krɨ)	കു (ku) കൂ (ku:) കൃ (krɨ)
2	Discard the usage of ര് (r) in the consonant sequence in the form of dot reph sign (˙). Alternate form ർ to be used.	i.ചൎക്ക (chark'ka) ii.പ്രാൎത്ഥന (prārt'thana)	ചർക്ക (chark'ka) പ്രാർത്ഥന (prārt'thana)
3	Discard the use of rare conjuncts by splitting them down into constituent consonant sequence separated by the virama sign.	i.ക്ത (kta) ii.ശ്ച (shcha)	ക്‌ത (kta) ശ്‌ച (shcha)
4	The consonant sign ര് (r) to be separated from the base grapheme using the alternate form ്ര.	i.പ്ര (pra) ii.ക്ര (kra)	പ്ര (pra) ക്ര (kra)

Figure 9: Summary of the government of Kerala's 'Malayalam Script—Adoption of New Script for Use' order– 23rd March 1971.

Orthographic knowledge can be further divided into two types: lexical orthographic knowledge and sublexical orthographic knowledge (Apel, 2011; Apel et al., 2019). Lexical orthographic knowledge is the collection of the (parts of) words an individual already knows (Cassar, 1997; Cunningham, 2006; Geva & Willows, 1994). Sublexical orthographic knowledge is the collection of rules or patterns connecting a grapheme(s) to a sound or an affix, and rules of occurrence of graphemes in context of each other and word positions. The two concepts do not have a hierarchy despite what the names suggest and are deployed in different reading/writing situations. Known and familiar words, which are in lexical orthographic knowledge, are fluently read and written with little cognitive efforts. On encountering novel words not in the lexical orthographic knowledge, sublexical orthographic knowledge is deployed (Apel et al., 2019). The most used orthographic knowledge measure task in studies (Sears et al., 2008; Tong et al., 2009) is the orthographic choice task. This task requires the participant to listen to the word spoken by the experimenter and then match it with the two written words in a word pair. The words in the word pair would have a correctly spelt word, an incorrectly spelt yet orthographically plausible version of the correctly spelt word (e.g., brain vs brane) or a homophone (e.g., pear vs pare). This is a judgement of the individual's lexical orthographic knowledge in the form of stored mental graphemic representations of words. The prevailing theories and research indicate that lexical and sublexical orthographic knowledge are independent but related concepts (Apel et al., 2019; Coltheart et al., 2001; Ehri, 2014).

Since orthographic knowledge is based on observation of patterns, it would be dependent on what script an individual was exposed to when s/he learnt to read and write, and the knowledge of its possible patterns formed over a period. Studies have indeed shown that the orthographic knowledge for a language form early on in a speaker's life, and is a function of exposure through education and reading habits (Apel, 2011; Apel et al., 2006; Masterson & Apel, 2010). Early reading habits are the precursors of the later orthographic knowledge (Majorano et al., 2021). There is also evidence for orthographic knowledge modification in children when they learn new segments in their language (Kessler et al., 2013; Lin et al., 2018; Treiman, 2017). These findings do indicate that children can acquire their mental representation of the script through their education, and later modify them based on reading or media exposure. However, there is not enough evidence connecting the progress of orthographic knowledge as age progresses beyond childhood.

This leads us to some interesting questions. Firstly, if the script of a language changes rapidly in a short time, then would there also be a difference in the orthographic knowledge of individuals who learnt to read and write before and after the change? This is not a straightforward question to answer, because an individual may have learnt to read and write in an old script to begin with but may be exposed to the new script in later years. It is not clear if and how the orthographic knowledge from the two scripts would interact with each other.

Secondly, would such a change reflect differently on the two levels of the orthographic knowledge? There are claims that say that sublexical orthographic knowledge gets formed first, and helps to develop the lexical orthographic knowledge as the learnt patterns are used in sounding out the novel words in children (Apel et al., 2006; Kessler et al., 2013; Treiman, 2017). However, it is also claimed that the stored mental representations of words, i.e., lexical orthographic knowledge would improve the knowledge of patterns, i.e., sublexical orthographic knowledge. Thus, the two levels are different but interrelated, and if what affects one level would also affect the other remains to be determined.

Finally, does 'simplification' of script provide benefit of improved reading and writing efficiency? How does this benefit, if any, interact with exposure to the script? Since an individual may perform greater amount of reading activity than writing activity (Mangen, 2018; Mangen & van der Weel, 2016; Mangen & Velay, 2010), it is possible that the two activities demonstrate different benefits.

Some of these questions can be tackled by running studies with people speaking the same language, but who were given literacy in different scripts; and/or people who were given literacy in one script but were exposed to a different script later in life. The historic Malayalam script reform move by the Kerala government in 1971 allows access to such people. Fifty-five years and older people in Kerala, the pre-reform group, had their elementary education in TS Malayalam before the reform of the government in 1971, whereas 54 years and younger, the post-reform group, had their elementary education after the reform in RS Malayalam. The years of a particular script exposure is a function of age as well. After the 1971 reform order by the government, there was a gradually increasing prevalence of RS in the print media and other publications such as administrative documents, court proceedings, textbooks, etc. A comparison of the orthographic knowledge, especially sublexical knowledge of the pre-reform and post-reform population would be interesting because the former had their entire elementary education in TS and later got exposed to print and other media in RS, while the latter had their education and media exposure both in a single script, i.e., RS.

Current study

The current study assessed the interaction of two different Malayalam scripts with lexical and sublexical orthographic knowledge.

We tested the interaction of scripts with lexical orthographic knowledge using a reading task. The interaction was measured as the processing demand (i.e. how much mental resources are engaged in doing a task) involved in reading the scripts. The rationale is that if there is sufficient lexical orthographic knowledge of the words, e.g., mental graphemic representation of the presented words, then there is little cognitive effort in recognising the word while reading; as a result, the reading time should be faster as compared to the cases where there is no lexical orthographic knowledge (Apel et al., 2019; Ehri, 2014).

Since the script in which the participants had their elementary education would comprise the lexical orthographic knowledge, we hypothesised that reading in that script would lead to lower processing demand and faster reading times. This means that for the pre-reform group, reading sentences in TS as compared to RS would induce less processing demand, which would be reflected as shorter reading time. Similarly, the post-reform group would experience less processing demand, and hence shorter reading times while reading sentences in RS.

We also examined the effect of script reform on sublexical orthographic knowledge by observing the writing skills of participants. Sublexical orthographic knowledge deals with the rules connecting spoken sound to written grapheme and how graphemes occur next to each other, hence would be activated while writing dictated speech. We hypothesised that, just like the lexical orthographic knowledge, the sublexical orthographic knowledge of the participants would enshrine the script that they learnt in their elementary education (Apel, 2011; Apel et al., 2019; Cunningham, 2006). Thus, it is this script they would use when asked to produce written material. This means, the pre-reform participants would choose to write in TS, and the post-reform participants would choose to write in RS.

However, since the reform was implemented almost 40 years ago, and print media had to adapt to RS, all the participants would have been exposed to RS in print. Even though reading the printed words deals primarily with lexical orthographic knowledge, it is possible that this significant exposure to the RS script had an impact on sublexical orthographic knowledge of the pre-reform group. This could be tested by observing the script that individuals subconsciously choose to write.

Any discrepancies in the usage of the script while reading or writing Malayalam by the participants from a particular age group would tell us about the impact of the script reform on orthographic knowledge for individuals. This would elucidate how script itself and the changes induced to it would affect the processing demands of individuals across age groups, and whether their elementary training and exposure to one script would have an impact on their reading and writing skills, shedding more light on orthographic knowledge, using data from a non-European language.

Method

Participants

The study was carried out in the state of Kerala in India. A total of 60 first language Malayalam speakers were recruited through the word of mouth and referrals. The participants were divided into two groups (30 each) based on age, and hence when they received their elementary education. The script reform order by the government was implemented in 1971. The pre-reform group, 55 years and above in age, were participants who received their elementary education in TS Malayalam before 1971 and the post-reform group, 54 years and below in age, were participants who received their elementary education in RS Malayalam post 1971 reform order.

Participants (Females = 39, Males = 21) ranged in age from 17 to 80 years with average 20.3 years of education. The participants had normal-to-corrected vision. As part of our pre-test measures the pre-reform group of 55 years and above participants were screened for cognitive status using the Addenbrooke's Cognitive Examination—Malayalam (M-ACE) test, which is the Malayalam adaptation of the Addenbrooke's Cognitive Examination (Kumar, 2004; Mathuranath et al., 2007; Menon et al., 2014). All participants from this selected group scored more than 88 points out of 100 on M-ACE with no indication of cognitive impairment.

Technique

Self-paced reading (SPR) is a computer-based psycholinguistic technique replicating real time language comprehension process through tasks similar to normal reading (Mitchell & Green, 1978). The words are presented one at a time on a computer screen, at a speed controlled by the reader, hence the name.

We implemented a non-cumulative SPR technique, in which all the words of the sentence are available on the screen but masked, i.e., not visible. Pressing a keyboard key unmasks only one word. Each subsequent keypress unmasks the next word while masking the previous one again. Thus, on successive keypresses, the words appear and disappear one by one, from left to right, in linear succession. The time taken in milliseconds to read the unmasked word, measured as the time between two successive keypresses, was called the reading time (RT) per stimulus word. The RT is indicative of the demands on the processing capacity, i.e. longer RT indicates higher demands on sentence processing or lower resources available. Being inexpensive, easy to implement, and portable, SPR technique was suitable for this study because the research had to be carried out at the homes of elderly participants.

Sentences were presented through a user interface, custom-made for the study on Linger software (v2.88) which is a standard Tcl/Tk application for performing SPR (Rohde, 2019), and because it supports both the Malayalam scripts (TS and RS). The font size was 45, and the font type was AnjaliNewLipi and AnjaliOldLipi for RS and TS, respectively.

In the second part of the study, each participant was orally dictated 5 sentences by the experimenter. These sentences were different from the previously mentioned 50 sentences. The same 5 sentences were dictated for all the participants. Each sentence comprised words that had 6–7 instances of glyphs from the 4 major reforms mentioned in Figure 9. This resulted in 30–35 instances each of testable glyphs from the written data of the participants.

Sentence material

For the present study, complex glyphs are considered to be the glyphs from TS which are formed when (i) two or more consonants are conjoined, or (ii) when vowel notations are

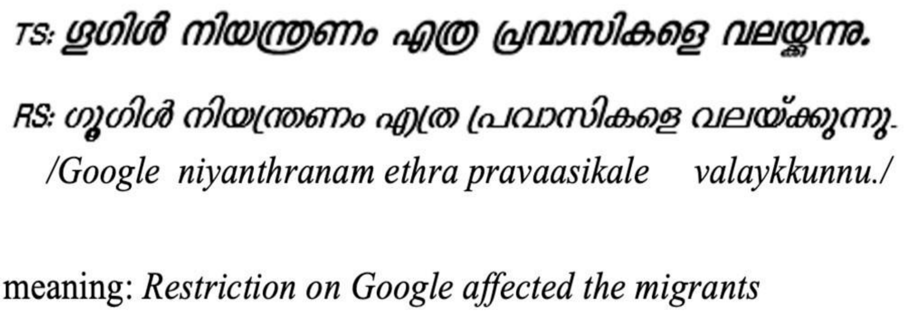

Figure 10: An example of a sentence in TS and RS.

attached to such consonant conjuncts or single consonants (Figure 9). A set of 50 Malayalam sentences in TS (total 323 words) was created, ensuring that each sentence had at least four instances of these complex glyphs. Within a sentence, the complex glyphs could be distributed across unique words, or two or more complex glyphs could occur within a single word. The latter case is classified as the Complex Word Type. Each sentence from the TS experiment set, thus, had at least 4 complex glyphs, but may or may not have the Complex Word Type. The TS set had a total of 59 words in the Complex Word Type category. Each sentence was meaningful as a whole, but the sentences were created in a way to avoid the words to be guessed from the context. A corresponding set of 50 sentences in RS was obtained by replacing the complex glyphs of TS script with glyphs in RS script (Refer to Figure 10 for an example). Each participant was presented with both the sets one after the other, i.e., total 100 sentences.

Procedure

Participants signed an informed consent form, followed by filling the demographic form, and undergoing the M-ACE test. Following this, the SPR task was administered by the experimenter on a 14-inch Lenovo laptop (AMD Ryzen 7). Participants sat approximately 80 cm from the laptop screen in a quiet place in their house. An absence of obvious distractions and human interruption was ensured during the experiment. The presentation of stimuli was controlled through the user interface. RT as the duration between two keypresses was measured in milliseconds (refer to Figure 11 for the schematic representation of the experimental set-up). Each participant read the same 50 Malayalam sentences, once in RS and once in TS. The order of the script, as well as the order of the sentences, were randomised across participants. An instruction page appeared for both the sets before the participants began the reading task. Additionally, the experimenter orally described the procedure to the participants. A short training session was provided to familiarise the participant with the interface and the requirements of the task without disclosing the use of or significance of the different scripts. To ensure the participants really read the words and were not skimming through the sentences, they were instructed to read the words aloud at speaking voice level. The reading activity was audio-recorded and transcribed for later confirmation. An automated break was programmed to be enforced after 25 sentences. The entire reading task lasted for approximately 30 minutes per participant. The study was conducted in accordance with the guidelines by the Institutional Ethics Committee of Birla Institute of Technology and Science, Pilani—Hyderabad Campus, India (Protocol Code—BITS-HYD/IHEC/2022/04).

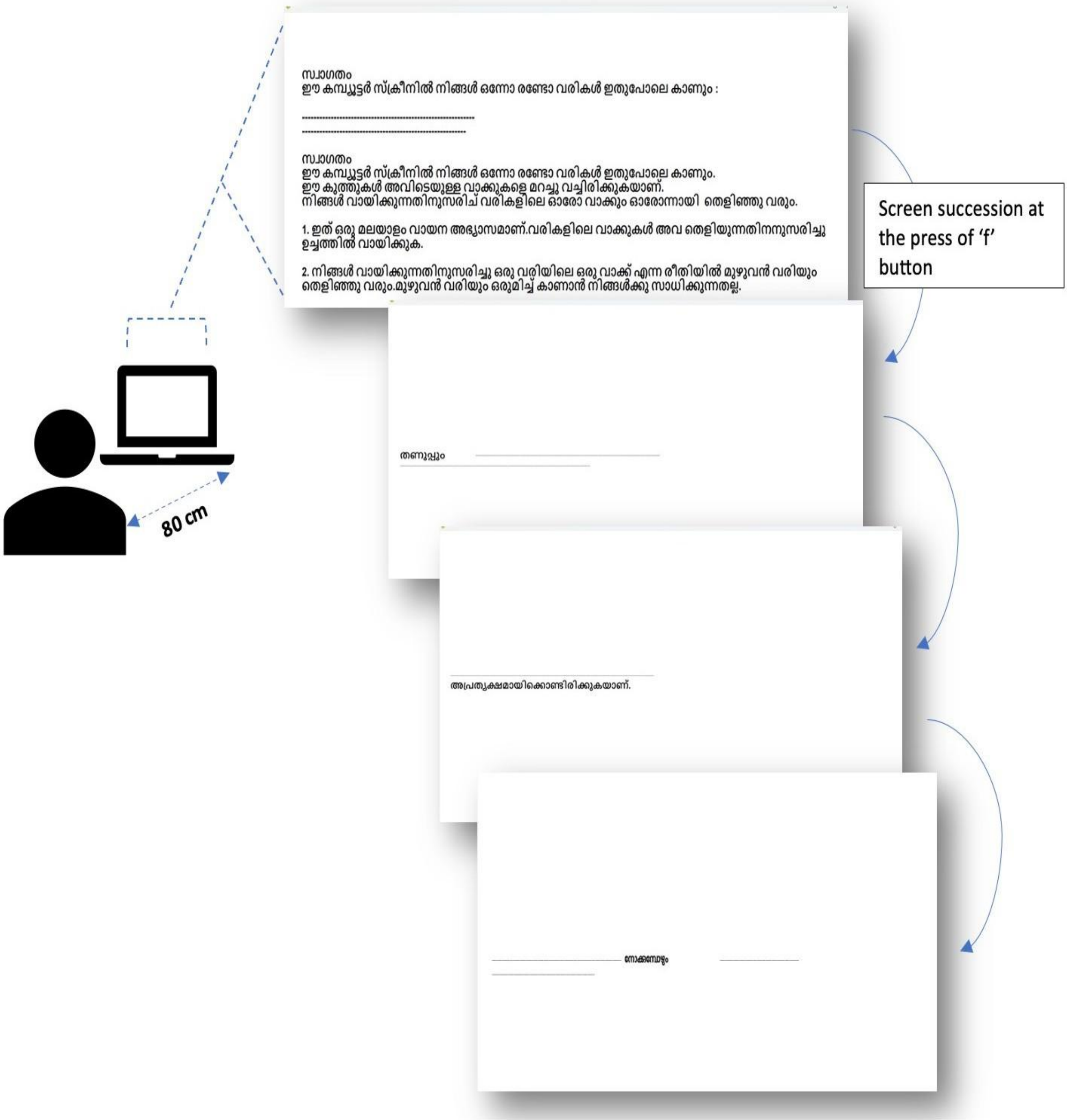

Figure 11: Schematic representation of the self-paced reading experiment. The participant is seated 80cm away from the laptop screen. The participant sees the instruction page, followed by the sentences in TS (or RS), each sentence appearing one word at a time.

Results

For the reading test, the RT in milliseconds for each sentence was summed up as cumulative RT for that sentence. The cumulative RT of the sentences was converted into seconds and averaged across participants for each of the groups. The values of the number of written glyphs were also averaged across participants for each of the two age groups. This data is presented in Table 2.

There was a total of 6000 observations (60 participants * 50 sentences * 2 scripts, i.e., TS and RS) for the reading time analyses. Gelman and Hill (2006) recommend using the log-transformed values of RT because the untransformed reading times fail to meet the assumptions of additivity and linearity. To transform the distribution to normality, the natural logarithm of RT (logRT) for each word read by the participants was calculated. Further analysis of reading time was done on these log-transformed values. Refer to the QQ plot in Figure 12.

The time taken to read each word with or without the complex glyphs was analysed using the open-source version of RStudio, integrated development environment (IDE) for R (64-bit, version 3.5.1). All the packages that were used within R were installed through the cloud library of R-Cran. For plotting the graphs from within R, Rcmdr package version 2.5–1 was used. A two-by-two design linear mixed model by REML ('lmerMod' package in R) was used. The fixed effects included the script type (TS and RS) and the age group (pre-reform, i.e., 55 years and above, and post-reform, i.e., 54 years and below). The random effect structure consisted of the random by-participants and by-item (word in a sentence) intercepts. The dependent variable was Log (RT). Degrees of freedom, and consequently, the p-values were estimated using Type II Wald chi-square tests.

Table 3 provides the output of the model. The model shows a main effect for script type and age group. The participants in the post-reform, i.e., 54 and below age group, took more time to read the sentences in TS (mean = 50.73 second, SD = 19.7) than to read the sentences in RS (mean = 37 second, SD = 14.35). Similarly, the participants in the pre-reform, i.e., 55 and above age group also took more time to read sentences in TS (mean = 56.03 second, SD = 17.96) than to read sentences in RS (mean = 43.36 second, SD = 16.37). There was also a script type * age group interaction. This suggests that irrespective of the age group, the time taken to read sentences was longer in TS than in RS. This indicates that reading words in TS induced greater processing demand for both the age groups.

In order to further evaluate the significant differences in the two scripts and their processing, the reading times of words with complex glyphs were separately analysed., i.e., TS and RS. For each participant, the RT in milliseconds for reading the complex glyph words was aggregated and averaged over the number of participants of the same age (Refer to Figure 13). It was then converted into seconds.

Table 2: Mean (and standard deviation) among script types and age groups for reading time in reading task and the distribution of written glyphs in writing task. The mean of the cumulative RT per sentence is expressed in seconds. The number of written glyphs for writing task totals to 35 per each script.

	Mean RT with Std. Dev. (in seconds)		***Mean Written Glyphs (SD)***	
	Post-reform (54 yrs. and below)	**Pre-reform (55 yrs. and above)**	**Post-reform (54 yrs. and below)**	**Pre-reform (55 yrs. and above)**
Reformed Script	37 (14.35)	43.36 (16.37)	22.17 (12.66)	4.39 (8.15)
Traditional Script	50.73 (19.7)	56.03 (17.96)	12.83 (12.66)	30.61 (8.15)

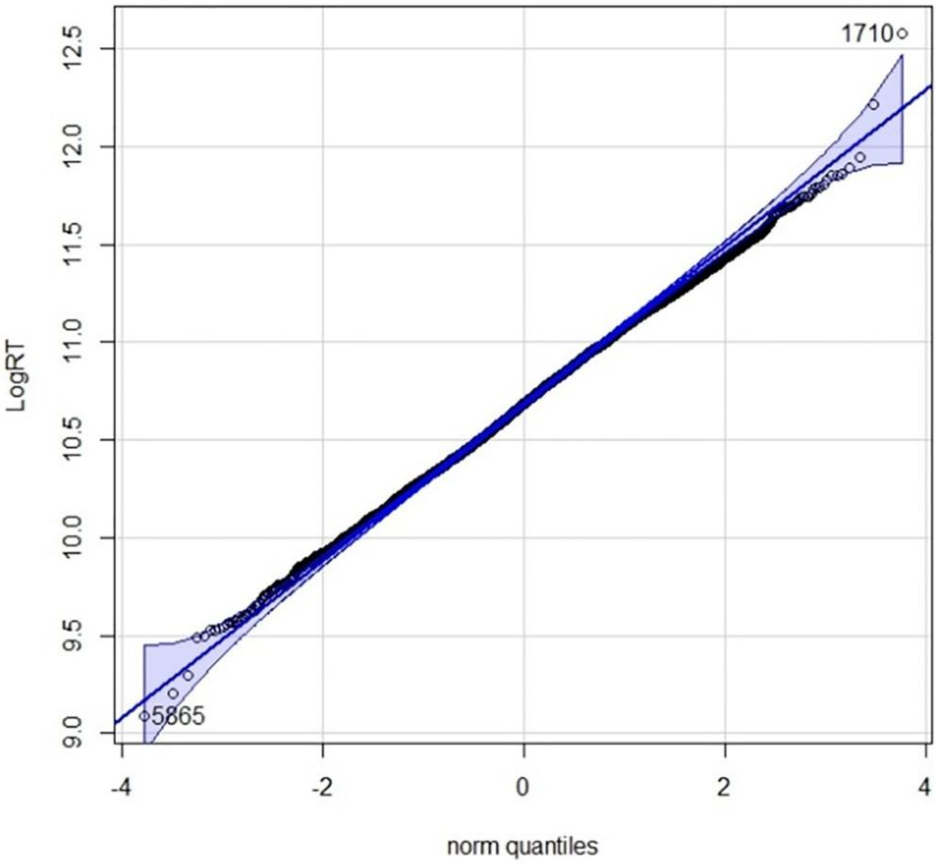

Figure 12: Quantile-Quantile plot of RT data points of the total 6000 observations showing normality in distribution.

*Table 3: Outputs of linear mixed effects model for the reading time data. Significance codes: : 0 '***' 0.001 '**' 0.01.*

Fixed effects	***Est***	***Std. Er.***	***t value***	***Variance***	***Std. Dev.***	***χ2***	***Pr(>|χ2|)***
(Intercept)	10.446	0.055	190.747	-	-	-	-
Script.Type	0.323	0.005	54.519	-	-	5171.317	< 2.2e-16 ***
Word.Type	-0.123	0.028	-4.376			19.1482	0.0000121 ***
Age.Group	0.167	0.068	2.439	-	-	4.257	0.03908 *
Script.Type X Age.Group	-0.052	0.008	-6.294	-	-	39.619	3.086e-10 ***
Random effects							
Participant (Int.)	-	-	-	0.069	0.264	-	-
Word (Int.)	-	-	-	0.029	0.17	-	-
Residual	-	-	-	0.025	0.159	-	-

The average RT of words with complex glyphs in the case of TS were found to be significantly higher (mean = 8.4 seconds, SD = 1.96) than that of RS (mean = 6.3 seconds, SD = 1.95). Refer to Figure 14 for a detailed script-wise RT distribution for these words with complex glyphs across ages. There is a significant effect of the words with complex glyphs written in TS on RT (Table 3, word type, p <0.001).

The sentences written by the participants from the two age groups were analysed. The mean of the distribution of each script type in writing the glyphs was calculated (i.e., what proportion of the 35 glyphs was written in RS vs. TS by each group). Refer to the data provided in Table 2. Participants in the post-reform group wrote more frequently in RS (mean = 22.17 glyphs, SD = 12.66) than in TS (mean = 12.83 glyphs, SD = 12.66). The participants in the pre-reform group, on the contrary, used more glyphs from the TS (mean = 30.61 glyphs, SD = 8.15) than glyphs from RS (mean = 4.39 glyphs, SD = 8.15). Refer to Figure 15 for the share of the two scripts in the total number of glyphs written by the participants as a function of age. We checked the correlation between the age group of the participants and the RS glyphs written by them using the Pearson's product-moment correlation. The r value was -0.73. The r value between the age group of participants and the TS glyphs written by them was 0.73. This indicates that the age group of participants has an inverse correlation with RS glyphs and a positive correlation with TS glyphs.

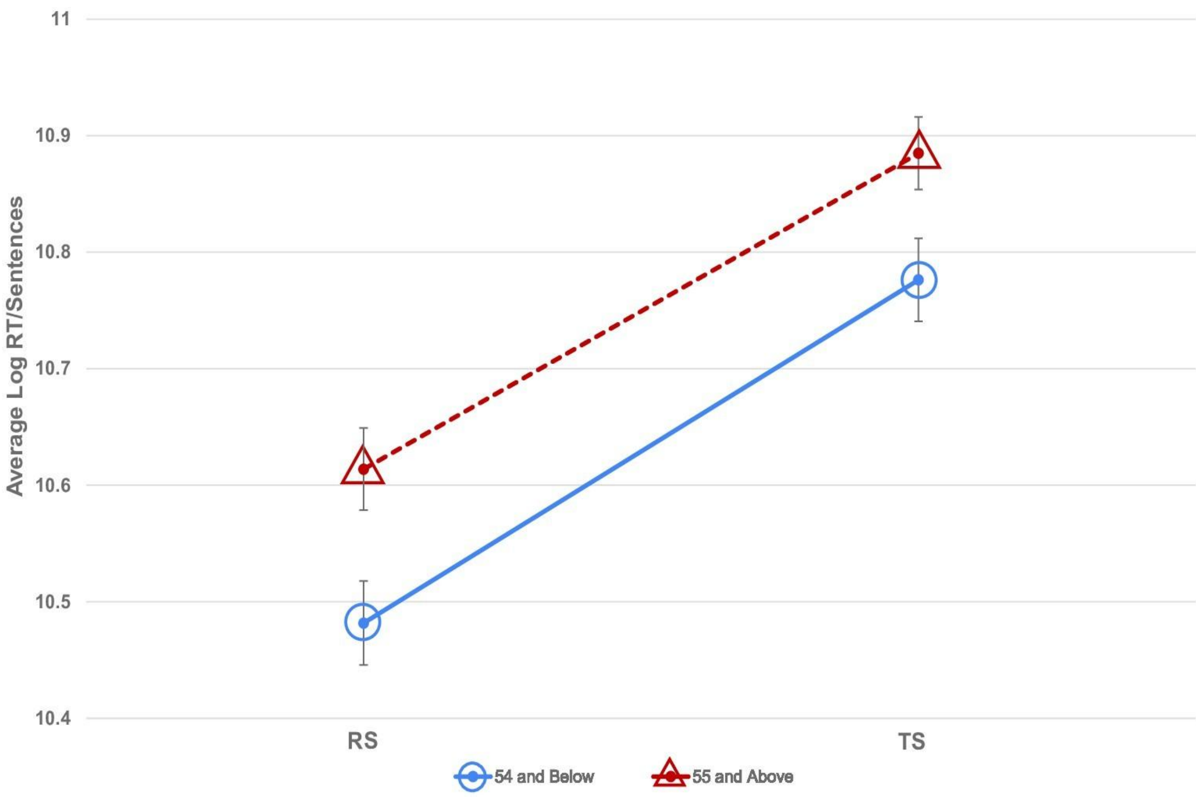

Figure 13: Plot of log-transformed means of reading time (RT), and the two-way interaction between the script types (RS and TS) and age group (54 and below; 55 and above). The y-axis does not begin at zero.

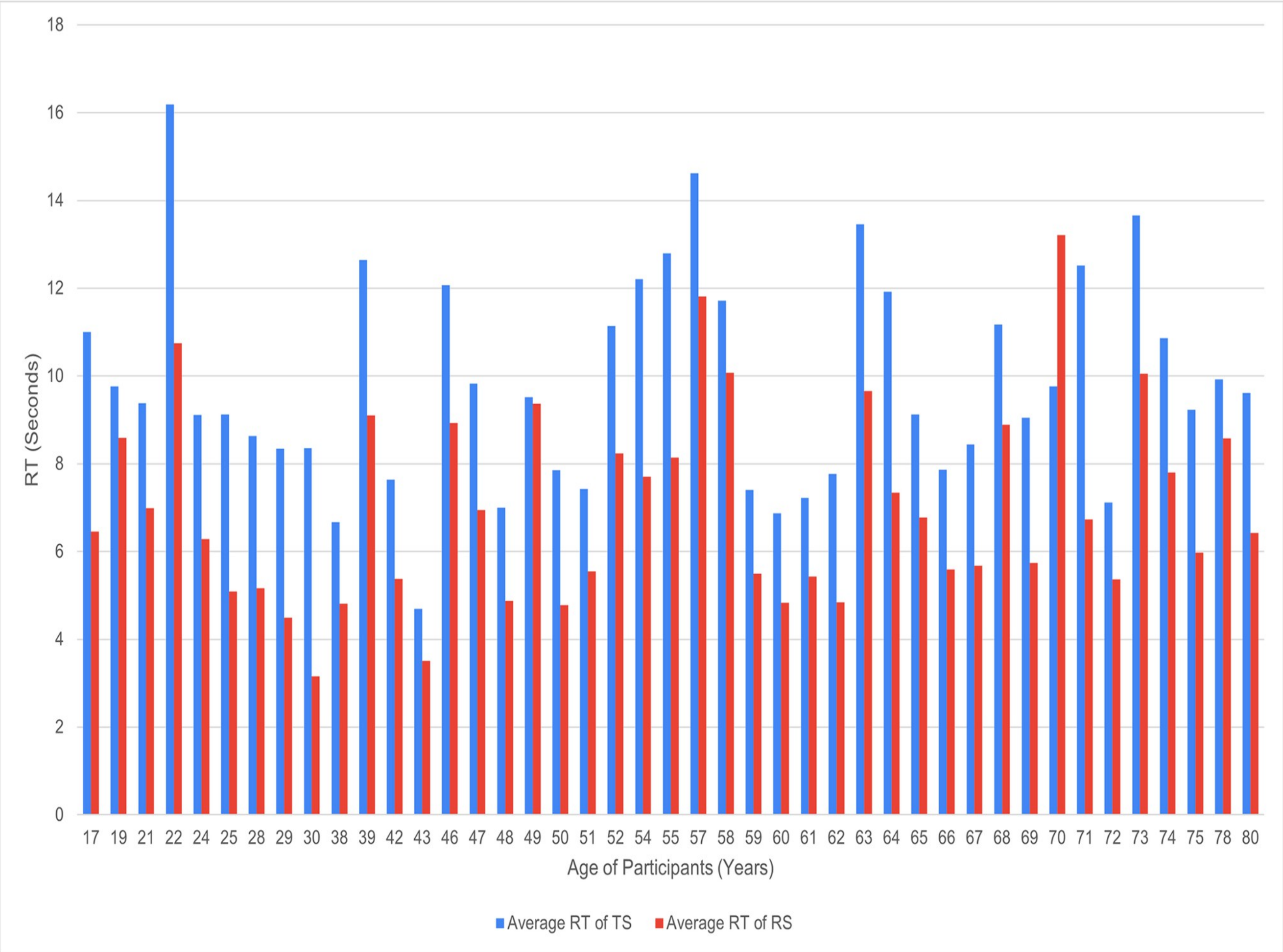

Figure 14: Script-wise distribution of RT taken to read words with complex glyphs by the participants across age.

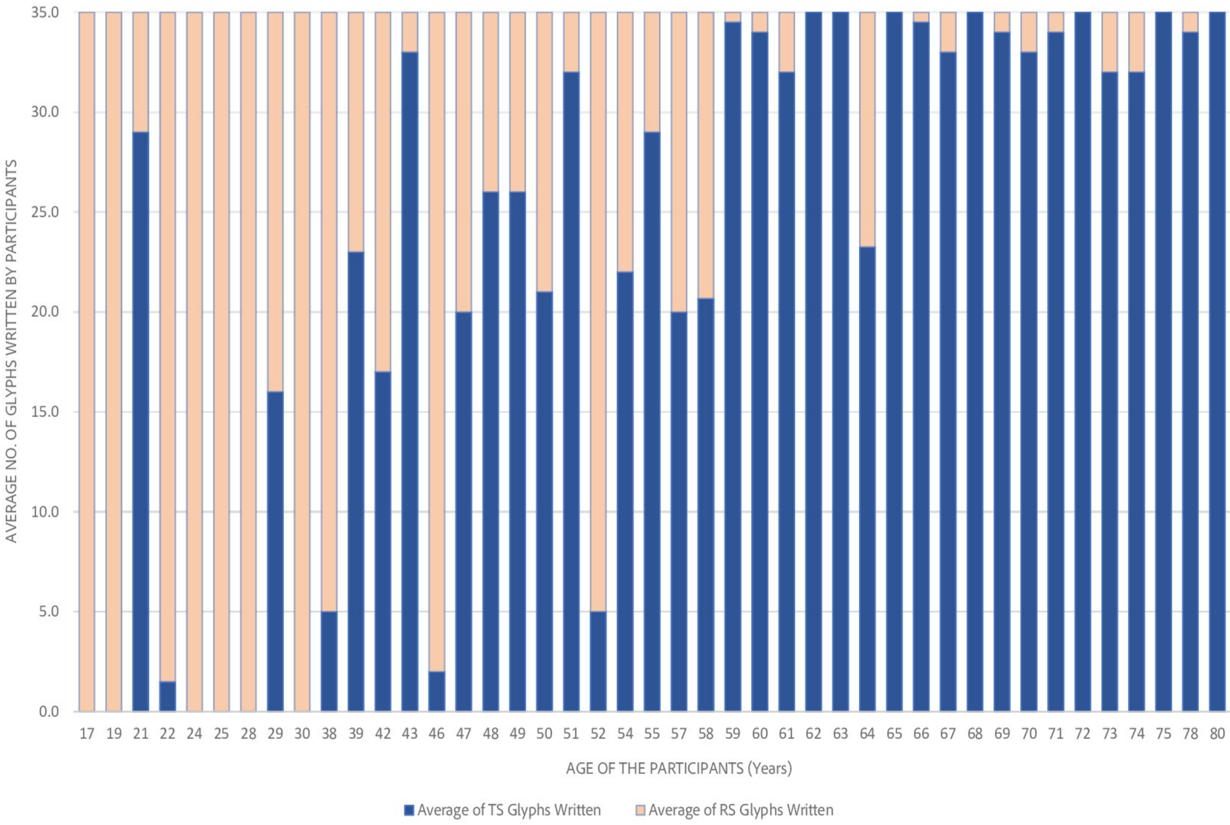

Figure 15: Script-wise distribution of the number of glyphs written by the participants across age.

Discussion

This study was conducted to see how a change in script interacts with the orthographic knowledge of the users of the script. This was achieved by comparing the reading and writing measures of participants who had their elementary education in TS Malayalam (pre-reform, i.e. 55 years and above) with those who had their preliminary education in RS Malayalam (post-reform, i.e. 54 years and below). Whereas the pre-reform group had ample exposure to TS, the post-reform group had exposure to mostly only RS.

First off, we found that both the groups were able to read both the scripts, though with some differences in performance, as shall be discussed later. It may be noted that though the reform was passed in 1971, the books and print media in TS that were in circulation before the reform were not banned and have continued to be in circulation even after the reform. For example, in spendthrift poor and middle-class Indian families, the school textbooks once bought may be used for home-based instruction year after year by younger learners within the family. The literary books and religious literature may be preserved for reading across years as well. Thus, print material in TS may have been in circulation alongside the material published in the RS. This might explain why even the younger people were able to read in TS, albeit slowly.

We had hypothesised that the lexical orthographic knowledge should primarily be composed of the script in which the participants had their elementary education, and this lexical orthographic knowledge would have an impact on script processing, i.e., reading. Based on this hypothesis, we expected that the pre-reform group participants would experience less processing demand when reading sentences in TS compared to RS, which should be reflected in shorter reading time (RT) for sentences in TS compared to RS. Similarly, the post-reform participants would experience more processing demand, reflected as longer RT while reading sentences in TS as compared to RS. However, against the expectation of the hypothesis, our results of the self-paced reading test show that the participants of both the groups were faster in reading sentences in RS as compared to the sentences in TS. Although the elderly pre-reform group took longer time than the younger post-reform group, which could be explained on the basis of a general slowdown of the executive functions in the elderly participants (Liu et al., 2017), the difference between RS and TS persisted within both the groups.

The fact that both the groups read faster in RS indicates that there was less processing demand in reading words in RS script. One indication of this is that the lexical orthographic knowledge for both the groups is largely composed of mental graphemic images of the words in RS, making the retrieval faster. This makes sense for the post-reform group who had received their elementary education in RS and not in TS. But for the pre-reform group, who had their education in TS, the reading results imply that either RS has completely replaced TS from the lexical orthographic knowledge, or more likely, RS co-exists with TS in lexical orthographic knowledge, and somehow RS has a significant presence, closer to retrieval. This could be true because reading is a skill that is practice-based, and hence would be sensitive to exposure. Since the print media and educational textbooks changed the fonts to RS from TS after the reform order, the reading exposure must be in RS.

An additional or alternate explanation is that RS is inherently easier to read as compared with TS, resulting in lower processing demand and shorter reading times. The consonant-vowel and consonant-consonant clusters in TS form a unique glyph different from either of the constituent letters. The letters are written as separate entities in RS. Because of this, RS is likely to have lower complexity, making it easier to read as compared to TS. An indication of evidence comes from Liu et al. (2017), who found that the elderly have lower thresholds for crowding of the letters in reading tasks. This seems like a tenable explanation, which can be further strengthened through the tests of discriminability.

The writing task was provided to observe the interaction of the scripts with sublexical orthographic knowledge. The task of writing the dictated speech would have activated the rules connecting sounds to graphemes and the occurrence of graphemes in each other's context, which is what sublexical orthographic knowledge deals with. The participants were asked to write the dictated sentences but were not overtly asked to pick any script. It was expected that when asked to produce written material, participants would use the script they had learnt in their elementary education, viz., the pre-reform participants would write in TS, and the post-reform participants would write in RS. Following the expectation, we found a clear relationship between the group type and the kind of glyphs written. The pre-reform group wrote primarily using the TS glyphs, whereas the post-reform group wrote primarily using the RS glyphs (Figure 15). This confirms that sublexical knowledge is indeed formed with the script one learns in elementary education. This is further confirmed by the correlation results.

For the pre-reform group, there is an inverse correlation with RS glyphs and a positive correlation with TS glyphs. This implies that the group type uses sublexical knowledge, the script in which they had elementary education to write in a dictation task.

The writing task had two outliers from the post-reform group. A 21-year-old participant and a 43-year-old participant wrote with the majority of TS glyphs instead of the expected RS glyphs (Figure 15). Both the participants reported taking a keen interest in the Malayalam language and its rich literary history, prompting a self-study of the TS glyphs using books printed in TS before the 1971 reform. On the other hand, a 64-year-old person in the pre-reform group wrote a large number of RS glyphs. This participant is a schoolteacher who teaches young pupils and employs RS for the daily teaching activities. This shows that a conscious effort and practice may help a person override the script acquired through their elementary education and thus reorganise their sublexical orthographic knowledge at a personal level.

One would expect both the lexical and sublexical orthographic knowledge to be composed of the same script. This does seem to be the case with the post-reform group. However, with the pre-reform group, the reading results indicate the lexical orthographic knowledge to be composed largely of RS. In contrast, the writing results indicate the sublexical orthographic knowledge to be composed of largely TS. Although the lexical orthographic knowledge seems to be updated to RS, why hasn't the writing and sublexical knowledge been updated to RS in this group? Is writing skill not exposure dependent?

The two persons in the post-reform group, as discussed earlier, have 'trained' themselves to use TS instead of RS in writing through exposure to older books. Additionally, one person in the pre-reform group shows a greater use of RS than others in her group due to using RS as required by her profession of school teaching. This indicates that writing skill may actually be exposure-dependent after all, and it should be possible to update it. The question is, why has the rest of the pre-reform group not updated the written script to RS? One of the explanations is that writing is a production-based skill. In order to update the writing skill, one needs to practise writing it. However, with the advent of the typewriters, computer-based text editing, larger circulation of printed material, audio-visual means of communication (e.g., telegraph, emails, etc.), there is a lesser opportunity for language users to write using RS, and hence update their sublexical orthographic knowledge.

This difference in the reading and writing results in the pre-reform group is a strong indicator that the orthographic knowledge indeed has two independent and separate levels. The sublexical orthographic knowledge from the results seems to be more rigid than lexical orthographic knowledge as it does not update with years of exposure, as seen with the pre-reform group participants. This also implies that reading and writing function differently in the case of scripts, and like orthographic knowledge, should be tested at two levels each in the case of lexical and sublexical knowledge.

The dichotomy similar to the two levels of orthographic knowledge has been posited in the Dual-Route Theory of reading aloud (Castles, 2006; Grainger & Ziegler, 2011). The theory suggests that while reading aloud, known words can be recognised by scanning the whole words and matching them with the mental database (Zorzi et al., 1998). This is akin to the mental graphemic representations of lexical orthographic knowledge. For unknown words, the reader takes the nonlexical route, which involves sounding out the word using the letter-sound rule system (Coltheart et al., 1993; Kirby & Savage, 2008). In the SPR test deployed in the study, to ensure the participants were not skimming through the sentences, they were instructed to read the words aloud at speaking voice level. For those words where the participants took longer time to read, which were unknown to them, they could have taken the non-lexical route of the Dual-Route Theory. Similarly, the shorter reading time taken by the participants while reading aloud could be the result of them matching the known words as an entire graphemic representation with their mental database. Thus, our findings fit well with the dual-route theory, except that the dual-route theory deals only with reading aloud, without referring to writing skills, whereas the present study explores that aspect as well.

Conclusion

Malayalam went through a script reform in the early 1970s, leading to simplifying ligatures and complex glyphs into simpler ones. The number of unique Malayalam graphemes went from almost 1200 in the traditional script (TS) to almost 90 graphemes in reformed script (RS) following the reform, leading to more efficient production of print material and media. People brought up before the reform had their elementary education in TS, whereas the ones brought up later had it in RS. This allows for a unique but continuously diminishing opportunity (because of the ageing population) to study the effect of script change on orthographic knowledge of a language. The study indicates that:

(i) Orthographic knowledge indeed seems to have two independent but related levels.

(ii) Reading skills are exposure dependent; hence, the lexical orthographic knowledge may get updated provided the condition of exposure.

(iii) Writing skill also seems exposure dependent, but there are fewer opportunities for language users to update their writing skills in modern times. Because of this, the sublexical orthographic knowledge seems more rigid than the lexical orthographic knowledge.

(iv) RS seems to induce less processing demand. This is a relevant result because the Kerala government had not considered the cognitive aspects of the change, such as its possible effects on orthographic knowledge of its speakers.

Gradually, it will be more and more difficult to do this kind of study again as the unique population who have been exposed to the two scripts continues to get diminished every day due to cognitive impairment, old age, and death. The current study finds further relevance in the fact that in a bid to restore the rich cultural heritage of the classical Malayalam language, the Kerala government is mulling over at least partially bringing back certain aspects of the old script (Manorama, 2021, 2022a, 2022b).

The existing consensus of a lexical and sublexical orthographic perspectives are mostly Anglo-centric in nature, with analyses mostly with Roman script or European alphabets. The current study, therefore, is a step towards bringing universality in the claim of the existence of the levels of orthographic knowledge, using a lesser studied script from the Indian subcontinent.

Data Availability Statement: Data are available at

https://osf.io/nh6we/?view_only=041a1bd6e09949e2abdc6bf8b3be0288

Chapter 5.
Letter Recognition Task amongst Malayalam and Non-Malayalam Speakers

Abstract: Research on reading has mostly looked at its three major levels - letters, words and sentences. Letters are the symbols in a script that encode human speech sounds, allowing for graphically representing a word, in effect allowing the formulation of sentences as a collection of written words. Correspondingly, reading text in a script involves visually processing the letters in words (and sentences) and decoding their sounds/pronunciation.
An important observation comes from the study reported in Nambiar et al. (2023). In the study, the authors noted that in 1971, the script for Malayalam language in India had been officially changed from Traditional Script (TS) to Reformed Script (RS) through Kerala government's script reform act. The TS to RS change was swift, universal, and comprehensive, leading to two distinct reader groups today, viz. experts in TS, who were taught to read and write pre-reform and only in TS, and experts in RS, who were taught to read and write post-reform and in only RS. The TS experts, who had their elementary education in TS, consistently chose TS for writing, yet read the sentences in RS faster than the sentences in TS. This is anomalous as we expected the experts in TS to read the sentences in TS faster, just like RS experts who read their sentences in RS faster. To test whether and how the complexity of features at the letter-level in both TS and RS affect fluency in reading across participants who are experts and novices in respective scripts, we conducted this follow-up study using the two levels of the orthographic knowledge theory framework. Our results show that TS/RS experts as well as novices in both scripts were faster in recognising TS letters as compared to RS letters. This suggests that reading fluency and two levels of orthographic knowledge should not be generalised across the three levels of reading. This also imply that expertise at sentence level reading of TS/RS does not imply expertise at the subsequent letter level reading.

What is reading?

Letters are the symbols in a script that encode human speech sounds, allowing for graphically representing a word, in effect allowing the formulation of sentences as a collection of written words. Correspondingly, reading text in a script involves visually processing the letters in words (and sentences) and decoding their sounds/pronunciation. Research on reading has mostly looked at its three major levels - letters, words and sentences (Marchetti & Mewhort, 1986; Rasinski, 2004; Stanovich, 1993). A fluent reading (and writing) process involves recognising, integrating, discriminating (apart from producing for writing) the features in a script at all the three levels with little cognitive effort. Most studies on fluency in reading have actually tested fluency directly in only one level (e.g. letters) while assuming that the results would entail fluency in the other two levels of reading as well (e.g. words and sentences) (Abadiano & Turner, 2005; Klauda & Guthrie, 2008; Naveenkumar et al., 2021; Schreiber, 1980; Stanovich, 1993). However, it remains to be shown with evidence that such an assumption about fluency across the three levels is valid. For a more comprehensive look, fluency could be tested for the two levels of orthographic knowledge for the three levels. Regarding this, we identified the following two research questions:

- Does fluency in reading stay uniform across its three levels - letters, words and sentences?
- For the three levels of reading, do the two levels of orthographic knowledge apply equally, or do they vary when we move from one level to the other, i.e., letters to words or words to sentences in a language?

Since most of the research in this area comes from the scripts of the European languages, it would be interesting to establish the answers to the aforementioned research questions in non-European scripts. Accordingly, to address these two questions, we set up this study, which examines the relationship of reading fluency across reading levels in a non-European script, using the two levels of the orthographic knowledge theory framework.

The motivation behind the study also comes from previous research on word- and sentence-level reading fluency of Traditional Script (TS) and Reformed Script (RS) of the Malayalam language, reported in Chapter 4. That research showed that one version of the Malayalam script, i.e. RS Malayalam, is processed faster by readers than TS Malayalam while reading (Nambiar et al., 2023). These results were obtained notwithstanding whether the participants' expertise lay in TS or RS of Malayalam. To better explain, RS experts, i.e. the participants who had their elementary education in RS, chose to write in RS and not in TS. They also read sentences faster in RS than TS, as was expected. TS experts, i.e. the participants who had their elementary education in TS, expectedly consistently chose TS for writing. However, against expectation, they read the sentences in RS faster than the sentences in TS.

Could this be because TS perhaps has more complex features than RS, leading to poorer letter recognition for its readers? We set up this study in a way that allowed us to test whether and how the complexity of features at the letter level affects fluency in reading. In the study, TS and RS reading fluency were analysed at the letter level by employing the same graphemes in TS and RS that were used in the preliminary study reported in Chapter 4. To rule out the effect of expertise on letter perception during the letter recognition task, we incorporated two types of participants. Type 1 had participants who were Malayalam speakers and who were experts in reading Malayalam TS and RS graphemes. Type 2 had participants without the knowledge of Malayalam graphemes.

The fluency in reading sentences could be because of the better retrieval of lexical orthographic knowledge of the words present in the sentences that were presented in the experiment. But when the letters in the same words are read non-fluently, does it mean that the lexical orthographic knowledge associated with the letters is different compared to that of the words?

Existing Theories on Letter Perception

In the field of experimental psychology, letter perception refers to the study of how individuals perceive and recognise each letter in isolation and within the context of words or sentences (Rasinski, 2004). Letter perception research aims to understand the cognitive processes and mechanisms involved in letter recognition, such as how quickly and accurately we identify letters, how we distinguish between different letters, and how contextual factors influence letter perception (Mcclelland & Rumelhart, 1981; Richman & Simon, 1989). Additionally, letter perception research also explores how individual differences, such as reading ability and language experience, influence letter recognition processes.

Experimental studies on letter perception have presented participants with visual stimuli of strings of letters, words or sentences and have measured their response times or accuracy in identifying specific letters (Grainger & Ziegler, 2011; Laham & Leth-Steensen, 2023; Rey et al., 2009). Some other studies have incorporated the factors that can affect letter perception, such as font type, letter size, word frequency, word context, and visual or cognitive interference (Bernard et al., 2016; Heilbron et al., 2020; Sanocki & Dyson, 2012). Despite taking into consideration the parameters that affect the identification of letters in isolation, these studies have not employed the same letters with their alteration in a word or sentence to see if the orthographic knowledge related to these letters in isolation affects the identification of letters the same way when they appear in sentences.

There are many theories and studies on letter perception, with a lack of consensus on what happens to our reading perception when we are presented with letters with or without the context of words and sentences. There are roughly two major observations of the studies and theories associated with this area:

1) Integration of features - Letters are not processed as individual features, i.e. strokes, curves, lines, etc., but are processed as units in which such features are integrated to form a composite shape.

2) Discrimination of features - Letters are processed as individual features, and discrimination of letters involves comparison of these individual features.

Some evidence for integration of features comes from the observation of the so-called Word Superiority Effect (Baron & Thurston, 1973; Marchetti & Mewhort, 1986). It suggests that people are generally faster and more accurate at identifying letters within a word than isolated letters or letters in non-word contexts. This effect highlights the role of context in letter perception.

According to Automatic Information Processing theory in reading, based on principles derived from information-processing theory (LaBerge & Samuels, 1974; Logan, 1978; Perea, 2012; Samuels, 1970), fluent reading develops through the gradual accumulation and integration of components which gets complex with practice. Logan (1985) emphasised that a crucial aspect of this integration is the development of a processing speed that, through repetition. It frees the mind from focusing on details, facilitates the overall reading process, shortens the time required, and reduces the extent to which conscious attention is needed for the process. The reading fluency increases as a result of developing automaticity in subskills. When a skill is characterised as automatic at a macro level, it signifies that the individual sub-skills at a more detailed or micro level, as well as their interplay, must also be performed automatically. This leads to a reduction in attentional demand on subsequent levels of reading such as words, phrases, and allows resources to be allocated to other areas, such as the semantic or meaning-based code (Norman, 1968). Though this holds true in the case of higher levels of reading, i.e., reading sentences, it has not been tested in the case of letters.

Automaticity and effect of exposure to a script are directly proportional in terms of reading fluency. Exposure plays a significant role in word recognition processes across different age groups. It influences vocabulary development and cognitive abilities, enhancing word processing efficiency. Research has focused on the influence of print exposure on vocabulary development, cognitive abilities, and word identification processes in children and young adults

(Arciuli & Simpson, 2012; Väisänen et al., 2014; Wolter & Apel, 2010). Higher levels of print exposure have been found to not only predict improved visual word recognition in developing readers, but also continue to impact word processing in college-age individuals. These effects persist even after accounting for general vocabulary ability, suggesting that print exposure contributes to word recognition processes beyond reading-related gains in vocabulary. Automaticity in reading enhances the efficiency of retrieving orthographic and lexical information. This increased efficiency in word processing may free up cognitive resources for higher-level language processes. Skilled readers and older adults with greater cumulative experience in lexical processing exhibit greater automaticity in visual word recognition. Higher levels of print exposure might also lead to improved possible word prediction ability while reading sentences (Payne et al., 2012; Sears et al., 2008). This leads to participants not waiting for the inputs in paced sentence reading tasks, resulting in skewed reading time measurements. This was taken into account in our previous research (Nambiar et al., 2023), and the strings of words were put together in such a way that the sequential word could not be guessed. In this follow-up study, to overcome this possible effect of automaticity of recognising letters, we employed a second group of participants (Type 2) with no expected mental representations of Malayalam letters and also tried to reduce this effect in participants with the knowledge of Malayalam letters (Type 1) by designing an experiment where the letters appear in isolation, and the participants differ in the level of their lexical orthographic knowledge of TS and RS. Automaticity is very well linked to the current lexical and sublexical orthographic knowledge at the print level and print exposure to a particular script.

The second observation mentioned earlier, i.e. discrimination of features, aligns with Lavie's Perceptual Load Theory (1995) on selective attention. PLT posits that the load induced by the tasks, irrespective of their linguistic nature or modality, would influence the performance of the participants. A heavy load task would call for less distractor interference, and a low load task would evoke more distractor interference, with performance better for the former than the latter scenario for the participants (Nambiar & Bhargava, 2023). Regarding the second observation mentioned before, a major theory is Verbal Coding Efficiency. According to this theory (C. Perfetti et al., 1979; C. A. Perfetti & Frishkoff, 2008; C. A. Perfetti & Lesgold, 1977), the impact of an unexpected event should depend on a reader's ability to process words at a fundamental level, specifically their ability to identify words out of context. A reader who can quickly identify words without context will do so regardless of the surrounding context. Contextual effects may take longer to apply than the reader's basic word processing rate. In such cases, the reader will not rely on context, and basic word identification will be completed before the slower context processing takes effect. On the other hand, a reader with a slower basic rate of word identification will be negatively influenced by a misleading context. This is because the contextual process provides conceptual guidance and creates specific expectations about the upcoming word. When an anomalous word is encountered in a sentence (e.g., "Here's the winning lottery *carrot*" instead of "Here's the winning lottery *ticket*") the processes that use visual information to retrieve a stored memory have to be restarted and carried out to completion. Simply guessing or accepting incomplete analysis will not be sufficient, leading to slower identification. These results of contextual influence on performance could be elucidated as the distractor interference on the performance of participants. Load here is imposed on the reader in the form of extra irrelevant graphemes in the form of context along with the target words.

Object-based theories on letter discrimination suggest that attention faces limitation with respect to the number of separate objects that can be perceived simultaneously. It means that the ability to discriminate between letters may be influenced by the number of letters present in the visual field. The evidence for this being the case in letter perception comes from the study that found that if participants are asked to identify a specific target letter among distractor letters quickly, their performance may be affected when the display contains a lot of distractor letters (Mcclelland & Rumelhart, 1981; Rey et al., 2009; Sanocki & Dyson, 2012). This limitation on the number of simultaneous letter perceptions may also be extended also to the number of separate discriminations that can be made. In the context of letter discrimination, this means that our ability to differentiate between different letters may be limited. For example, researchers have conducted experiments where participants are presented with pairs of letters and asked to determine whether the two letters are the same or different (Janini et al., 2022; Laham & Leth-Steensen, 2023; Rey et al., 2009; Sanocki & Dyson, 2012). These studies often involve manipulating factors such as letter similarity, spacing between letters, or the presence of distracting elements. The results show that participants have difficulty discriminating between letters that are very similar in shape or when letters are densely packed together, supporting the idea of limitations in discriminating between letters.

Space-based theories suggest that attention faces limitations with respect to the spatial area from which information can be extracted. In the context of letter discrimination, this implies that our attention may have a limited spatial focus when perceiving and distinguishing letters. For example, in perceptual span studies, participants were presented with visual displays containing letters arranged in different spatial configurations (Deng et al., 2019; Franceschini et al., 2012; Laski et al., 2013). The participants were instructed to focus their attention on a specific region or a specific letter. Results showed that participants' discrimination performance is better when attention is directed to a particular location or letter than when attention is distributed across a larger spatial area (Franceschini et al., 2012; Mastroberardino et al., 2015). This supports the idea that attention has a limited spatial scope when it comes to perceiving and discriminating between letters.

A major theory in observation 2 mentioned earlier is the Feature Integration Theory (FIT), which proposes that the visual system initially decomposes a visual scene into its individual features, such as colour, shape, and orientation. These features are processed in parallel and automatically in a pre-attentive stage. In the context of letter discrimination, this means that when we encounter letters, our visual system extracts their individual features, such as the shape of the letters and the presence of specific contours or strokes. However, selective attention is necessary for accurate discrimination by binding these features together. According to FIT, the pre-attentive stage in letter discrimination involves the automatic processing of these individual features.

Our two categories of letter recognition closely follow Apel's Orthographic knowledge theory (2011), where there are stored mental representations of words or phrases, which aid the reader to quickly identify the words, resulting in faster reading or faster comprehension. According to the two-level orthographic knowledge view (Apel et al., 2019), fluency in reading occurs when an individual can recognise written words with less cognitive effort. This happens when the reader employs the lexical orthographic knowledge or, in other words, efficiently uses graphemic representations of known words to the reader, which are readily available in their memory, leading to a fluent reading. The recognition of letters in this situation is faster due to perceiving the word level as an integrated unit rather than the subsequent features. Lexical Orthographic knowledge, therefore, is in line with the feature integration theories of letter recognition.

When the graphemic representation of words is not available, the reader employs the sublexical level of orthographic knowledge. At this level, the features of unknown words are decoded for word recognition and fluent reading. Word recognition at the sublexical orthographic knowledge level can follow multiple patterns like recognition of the possible orthographic sequences (consonant or vowel sequences) and possible frequencies of word representations, such as frequent word representations as compared to infrequent representations. Word recognition at sublexical orthographic level can happen at the letter level when the readers spell the letters of unknown words to process the word. The readers do a phonological, letter sound decoding for fluent reading. This is called the alphabetic principle (Apel et al., 2006; Arciuli & Simpson, 2012). This is in line with observation 2 of discrimination of feature studies of reading fluency. The participant would initiate sublexical orthographic knowledge of subsequent levels of reading when there isn't one available for one of the levels of reading, i.e., use sublexical knowledge of letters used in a word when a graphemic representation of the word itself does not exist in the participants' reading knowledge base.

Since it is a function of the three major levels of reading- letters, words and sentences, reading fluency should always be tested for all three levels. For this study, we consider reading as a complex process that is a combination of both the categories of theories discussed till now, i.e., integration and discrimination of graphemic features present in letters, words and sentences.

Print exposure leading is interlinked with forming lexical knowledge of written words. We need to check whether that was one of the reasons why, in our preliminary study, all the participants, irrespective of their sublexical knowledge level, were able to read RS script words and sentences faster compared to TS words and sentences. One of the reliable explanations for this outcome that the researchers identified in the initial study is that exposure to a particular script makes its users an expert in that particular script, leading to better retrieval of mental graphemic representations. In other words, experts in a script are individuals with more mental graphemic representations of words in their respective scripts. Here, it is possible to assume that the participants then would read RS letters faster too, compared to TS script letters, merely because of greater exposure and forming of lexical orthographic knowledge in that script. If the assumption does not stand, it points to the possibility of having separate lexical knowledge bases within a script for its three levels of reading.

In order to discuss the process of reading in any script, it is also essential to look at the two levels of orthographic knowledge across the three levels of reading. As discussed, our first step was to start at the sentence and word levels of an alphasyllabary Malayalam script and see the effects of two levels of orthographic knowledge (Nambiar et al., 2023) on reading. Our preliminary study looked at the fluency of reading at the sentence and word levels and writing skills of participants who were experts in one of the scripts in Malayalam, either RS or TS. The current study is our attempt at analysing reading fluency at the letter level and understanding letter perception in alphasyllabary scripts of Malayalam. There is a dearth of literature where there is an integration of levels of reading - letters, words and sentences with the reading process in general. Most of the studies on reading have tried to juxtapose or generalise the results of one level of reading to the other level. This study tries to bridge this gap by conducting a follow-up study on reading fluency of letters in alphasyllabary Malayalam with two letter recognition experiments in TS and RS Malayalam across participants with the knowledge of the TS and RS scripts (Malayalam speakers) and without the knowledge of the TS and RS scripts (non-Malayalam speakers).

Current Study

The current study assessed letter recognition in Malayalam using its two scripts - RS and TS with two groups of participants. We used a match-mismatch binary decision task for letter recognition (see Chapter 4, section Technique for a detailed description) and tested separately for both scripts across the two participant types. The study, in order to test the two scripts separately across participant types, was divided into two experiments. Experiment 1 had graphemes from RS Malayalam, and Experiment 2 had graphemes from TS Malayalam for letter recognition. Script translates as ‘Lipi’ in Malayalam, and this study has called the script types, namely RS and TS, ‘Lipi types’ for developing the two experiments.

The rationale is that readers who processed the sentences in RS faster than the sentences in TS Malayalam would identify/discriminate the letters in RS faster than the letters in TS. They would have sufficient lexical orthographic knowledge of the letters in TS, e.g., graphemic mental representation of the presented words; then, there is little cognitive effort in recognising the TS letters as compared to the RS letters while reading. As a result, the RT should be faster than in cases with TS letters. The results would inform us whether exposure to a given script is a major factor in letter recognition. This is important for the following reasons - 1) From the sentence processing results, we see that lexical orthographic knowledge at the sentence level of reading is exposure-dependent. 2) Type 1 participants, or the Malayalam speakers with their sublexical knowledge in TS, still read RS faster. However, from the current study, we see that participants whose are experts in Malayalam orthography and those who are novices in Malayalam orthography discriminate the TS letters much faster than the RS letters.

Participants

Experiments 1 and 2 had a total of thirty-two participants divided into two types (16 in each) based on their knowledge of Malayalam scripts (RS and TS). Participants ranged in age from 29 to 77 years in Type 1 (mean age = 56.187; females = 11) and 29 to 73 in Type 2 (mean age = 55.125; females = 8) and reported normal to corrected hearing and vision. Each participant from both these types took part in experiments 1 and 2 on the same day. They provided informed consent before their participation. The speakers of Malayalam with knowledge of Malayalam scripts TS and RS were in Type 1. Non-speakers of Malayalam with no knowledge of RS and TS scripts were in Type 2. Type 1 participants received their elementary education in either TS or RS Malayalam and were the same participants who were part of the preliminary study conducted on Malayalam Orthography by the authors in 2022 to ensure the reliability of the results (Nambiar et al., 2023), and the Type 2 participants received no training in Malayalam.

Technique and Letter Material

Keyman 16.0 software was used to type and create 96 pixels/inch PNG images of graphemes in TS and RS. These images were then incorporated into PsychoPy Experiment Builder version

3.0. for developing the experiments 1 and 2 (Refer to Figure 16). The Binary Decision Task on Letter Recognition was created using PsychoPy. Rstudio, an open-source version (64-bit, version 3.5.1), was employed for the data analyses.

Procedure

For experiments 1 and 2, participants signed an informed consent form. The experiments were administered by the experimenter on a 14-inch Lenovo Laptop (AMD Ryzen 7). Participants received verbal instructions and an on-screen training session before they performed both experiments. They were seated approximately 40 cm from the laptop screen and recorded their responses by clicking either the 'y' or 'n' buttons on the keyboard. The experimenter ensured that the participants sat comfortably away from obvious sensory distractors and other human interruptions. PsychoPy ensured a time-controlled presentation of the visual input. The responses via the keyboard clicks measured the RT in milliseconds and the accuracy scores (1 for correct response and 0 for incorrect response).

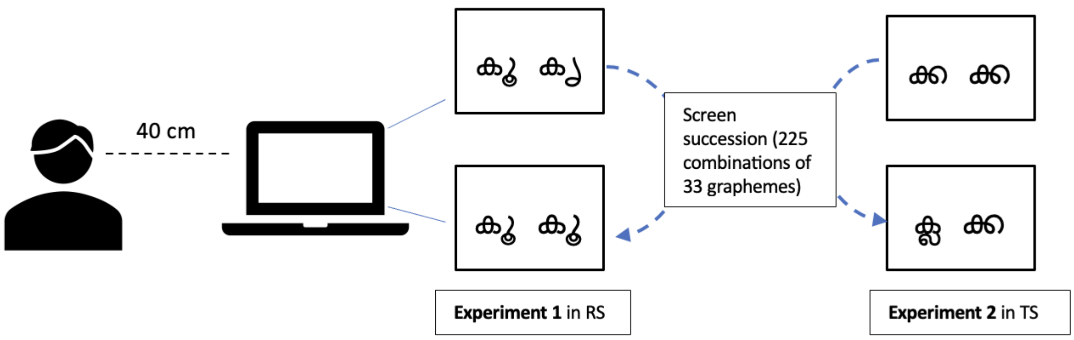

Figure 16: A schematic representation of the Malayalam Binary Decision Task for the letter recognition experiments. Experiment 1 had letters from the RS Malayalam, and experiment 2 had letters from the TS Malayalam. The screen succession happened at the press of 'y' (when the glyphs matched) and 'n' (when the glyphs did not match) buttons on the keyboard by the participants across Lipi Types and Participant Types.

Results

The G* Power test was conducted to find the power (1- b err prob) using an F test – ANOVA: repeated measures within-between interaction. The test was done post hoc to understand the achieved power. The effect size (f) was 0.25, and the error probability was set at 0.05. The power achieved was (1- b err prob) = 0.911

The plot of mean response time scores for experiments 1 and 2 is shown in **Figure** 17. The RT for both the binary letter recognition tasks in TS and RS was converted into seconds and averaged across participant types - Malayalam speakers and non-Malayalam speakers. There was a total of 7200 observations (32 participants * 225 Glyphs * 2 scripts, i.e., TS and RS) for RT and Accuracy score analyses. The RT to complete the binary decision tasks was analysed using an open-source version of RStudio (integrated development environment (IDE) for R (64-bit, version 3.5.2). The cloud library service R-Cran was used to install the packages used for analyses and plotting graphs. An Rcmdr Linear Model.RT 4 was used to do a Multiple Linear Regression. The independent variables here are the Lipi Type, Participant Type and Condition. The dependent variables are Accuracy scores and RT.

The type of participant (Malayalam or Non-Malayalam speakers) has a significant effect on reaction time with a p-value of 2.42e-08. The interaction between participant type and script type, too, has a significant effect on reaction time with a p-value of 0.00113. The interaction between script type and condition has a significant effect on reaction time ($p < 0.001$).

The accuracy scores for the binary decision task (1 for correct response and 0 for incorrect response) were averaged across participants from both participant groups (Refer to Table 5).

The type of participant (Malayalam or Non-Malayalam speakers) has a significant effect on accuracy ($p<0.001$). The type of script (Traditional or Reformed) and the condition (Match or Mismatch) had a significant effect on accuracy (both had values of $p<0.001$). There was a significant interaction between script type and condition (Match or Mismatch) on accuracy with a p-value of 6.95e-11.

*Table 4: Outputs of linear regression model for the Reaction Time (RT) data. Significance codes: *** < 0.001, ** < 0.01, * < 0.05,.< 0.1.*

Coefficients:	***Est***	***Std. Er.***	***t value***	***Pr(>|t|)***
(Intercept)	6.59779	0.01418	465.371	< 2e-16 ***
Participant.Type [Malayalam: NonMalayalam]	0.11193	0.02005	5.582	2.42e-08 ***
Lipi Type[Traditional Script:ReformedScript]	-0.03537	0.02005	-1.764	0.07777.
Condition [Match: Mismatch]	-0.12292	0.01535	-8.009	1.24e-15 ***
Participant Type X Lipi Type	-0.09236	0.02835	-3.257	0.00113 **
Participant Type X Condition	0.01363	0.02170	0.628	0.52992
Lipi Type X Condition	0.05963	0.02170	2.748	0.00601 **
Participant Type X Lipi Type X Condition	0.02186	0.03070	0.712	0.47644

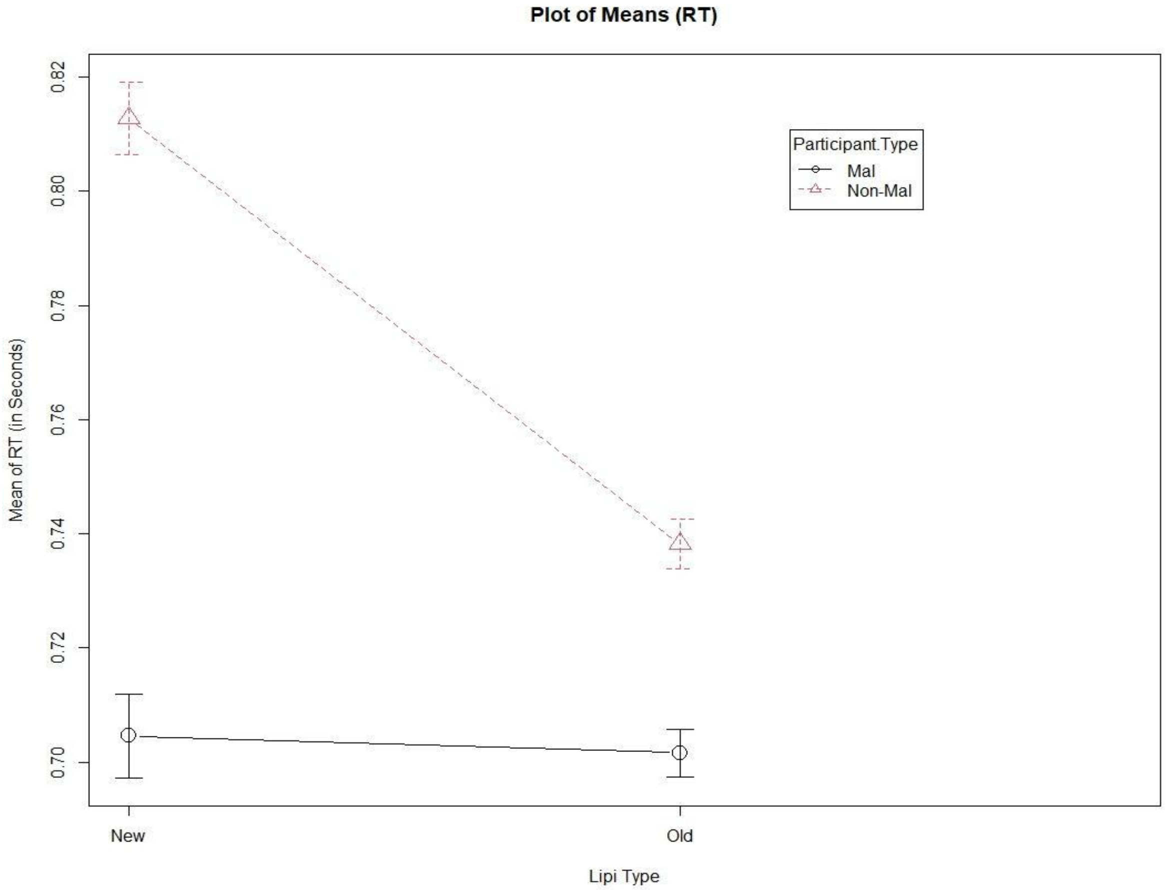

Figure 17: Plot of means of response time (RT) and the two-way interaction between the Lipi type (RS and TS) and participant type (Malayalam and Non-Malayalam pa). The y-axis does not begin at zero.

*Table 5: Outputs of linear regression model for the Accuracy Scores. Significance codes: *** < 0.001, ** < 0.01, * < 0.05,.< 0.1.*

Coefficients:	***Est***	***Std. Er.***	***t value***	***Pr(>|t|)***
(Intercept)	0.854167	0.007390	115.592	< 2e-16 ***
Participant.Type [Mal: NonMal]	-0.035985	0.010450	-3.443	0.000576 ***
Lipi Type[Old: New]	0.085227	0.010450	8.155	3.76e-16 ***
Condition [Match: Mismatch]	0.128255	0.007999	16.033	< 2e-16 ***
Participant Type X Lipi Type	0.034091	0.014779	2.307	0.021085 *
Participant Type X Condition	0.027196	0.011313	2.404	0.016230 *
Lipi Type X Condition	-0.073834	0.011313	-6.527	6.95e-11 ***
Participant Type X Lipi Type X Condition	-0.038648	0.015999	-2.416	0.015717 *

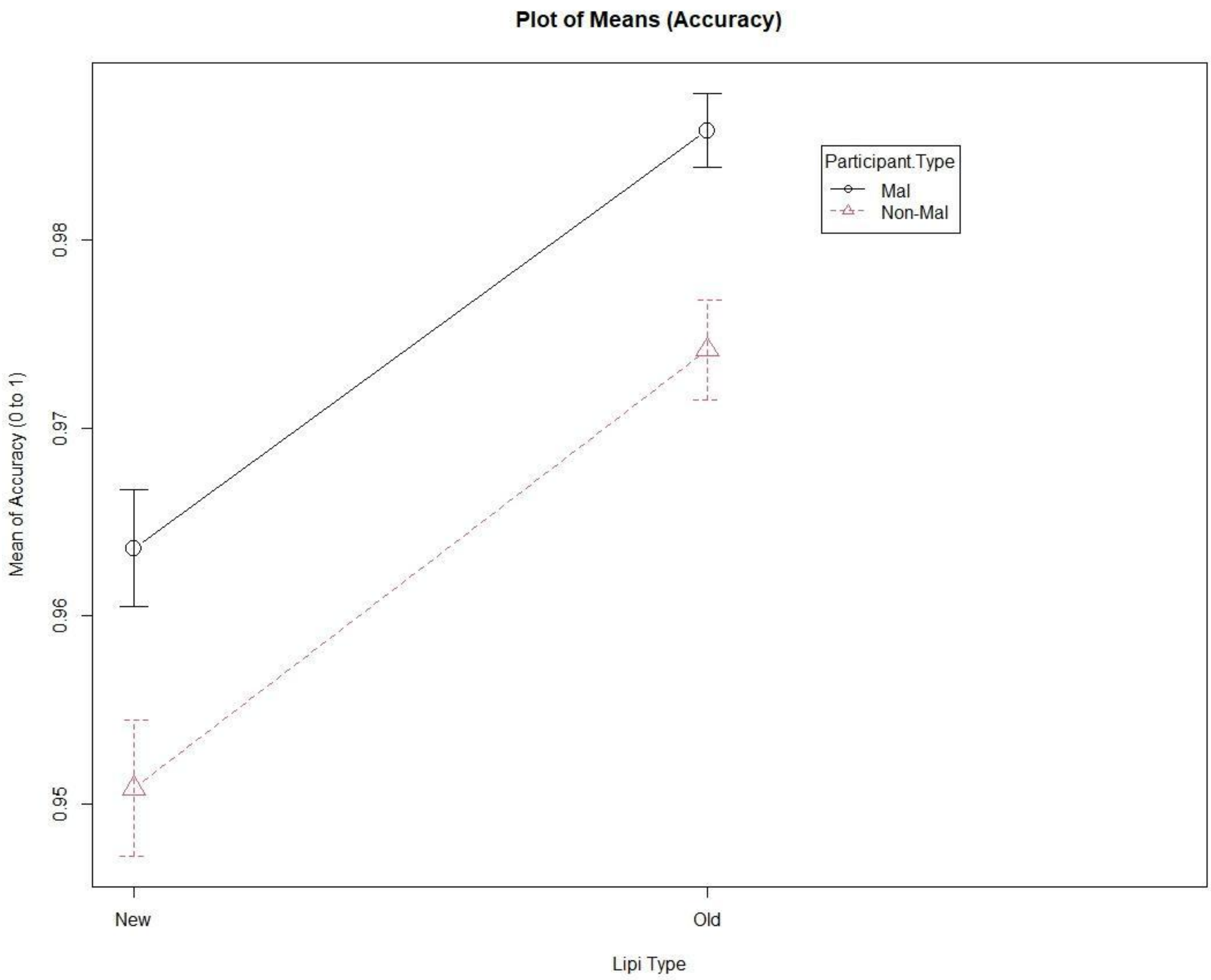

Figure 18: Plot of mean accuracy scores and the two-way interaction between the script types (RS and TS) and participant types (Malayalam and Non-Malayalam). The y-axis does not begin at zero.

Table 6: Average accuracy scores of participant type (Malayalam and Non-Malayalam speakers) across Match-Mismatch condition in Lipi Type.

Average Accuracy Scores (0-1)	**Mal**		**Mal Total**	**Non-Mal**		**Non-Mal Total**	**Grand Total**
Row Labels	**New (Exp 1)**	**Old (Exp 2)**		**New (Exp 1)**	**Old (Exp 2)**		
Match	0.854	0.939	0.897	0.818	0.938	0.878	0.887
Mismatch	0.982	0.994	0.988	0.974	0.980	0.977	0.983
Grand Total	0.964	0.986	0.975	0.951	0.974	0.963	0.969

Table 7: Average RTs of participant type (Malayalam and Non-Malayalam speakers) across Match-Mismatch condition in Lipi Type.

Average of RT in seconds	**Mal**		**Mal Total**	**Non-Mal**		**Non-Mal Total**	**Grand Total**
Row Labels	**New (Exp 1)**	**Old (Exp 2)**		**New (Exp 1)**	**Old (Exp 2)**		
Match	0.774	0.727	0.751	0.892	0.743	0.818	0.784
Mismatch	0.693	0.697	0.695	0.799	0.737	0.768	0.732
Grand Total	0.705	0.702	0.703	0.813	0.738	0.776	0.739

Discussion

The results of this follow-up study on letter recognition as part of the broader reading fluency and orthographic knowledge levels confirm the existence of two levels of orthographic knowledge bases but separate for the three levels of reading. Having lexical and sublexical levels of orthographic knowledge for a particular script does not entail that the levels of knowledge are rigid and the same for all its levels of reading, namely letters, words and sentences. The differences in performance for the same participant across reading levels in a given script with the exact same graphemes used in letters, words and sentences establish the possibility of multi-layered separate orthographic knowledge levels. This difference in performance in letter recognition could be more perceptual and extrinsic in nature than being intrinsic. If it were not extrinsic in nature, we would have seen no difference in performance between Type 1 and 2 participants, with Type 1 being experts in Malayalam scripts and the latter with no knowledge of the chosen script.

Beyond the predictable differences in performances of Type 2 participants, i.e., Type 1 experts' RT being less compared to Type 2 novices, we see a significant effect on RTs and accuracy scores across the participant types. Irrespective of the participant types, both groups took a longer duration in Task 1 -- match-mismatch binary decision task in RS script. The accuracy scores, too, were lower for Task 1, irrespective of participant type.

Our first question is whether fluency stays uniform in three levels of reading when the same graphemes are used across levels for Type 1 and 2 participants. Irrespective of the expertise and exposure of Type 1 participants, the RT scores for the RS Binary letter recognition task were higher compared to the TS task. The same trend was seen with Type 2 participants. The possible explanation here is that letter-level identification usually does not happen like word recognition tasks or comprehension tasks with sentences. Here, the letters in isolation, in fact, are broken down into features by the participants to differentiate one grapheme from the other. When the features are discriminated for recognition, we have to consider the perceptual space taken by the grapheme. If the grapheme is crowded feature-wise, we can assume that it creates perceptual graphemic load or 'Scriptual Load' for the participants. There is a lower verbal coding efficiency in the case of RS letters due to too many features present within an RS glyph. This creates a higher perceptual load, leading to slower performance across participant types. Thus, here in the study, as the RS graphemes take perceptually more space and processing it linearly would take more attentional resources. We can conclude that RS graphemes create a scriptural load for the readers, hence the longer RTs, irrespective of the participant type. In spite of being able to read the sentences in RS faster compared to TS, Type 1 participants were not able to recognise the RS graphemes as quickly as the TS graphemes. The possible high glyph density of RS letters can explain this anomaly. Grapheme density is the higher feature density in the written form of a letter caused by the multiple features in a single grapheme. Another possible reason for the anomaly is that compared to RS graphemes, features in TS graphemes could be less similar to each other, causing better integration of the features of TS letters. Higher similarity between features in a grapheme would lead to a higher perceptual load on the participants. The similarity between features, thus, makes it hard for both the participant types to discriminate the RS letters. Interestingly, we do not see the effect of expertise on letter recognition tasks. The high perceptual load imposed by a higher number of features in the RS letters should not have affected Malayalam speakers, which resulted in lower accuracy scores in the letter recognition tasks. It suggests that sentences and letters in a given script and their reading fluency do not originate from the same schema or orthographic knowledge. Malayalam participants, who are biscriptals with knowledge of both TS and RS scripts, have separate orthographic knowledge levels for sentences and the letters. The perceptual load does not interrupt RS sentence processing but affects the RS letter recognition explains the same. The exposure to print also does not seem to affect the letter-level recognition of TS and RS letters. The RS script is heavily popular in media in Kerala, which was one of the possible reasons for the faster processing of RS sentences by TS experts. However, the current study results suggest that print exposure to RS letters did not make it easier to process for the Malayalam participants. There is no lexical orthographic knowledge or graphemic images of letters, formed in the case of letters for the participants. This again emphasises that at the letter level processing, i.e., when the letters are in isolation, the readers or the participants break down the letters into subsequent features leading to high perceptual load in participants due to similar features in RS letters. One limitation in the task designed for Type 2 participants who are novices in Malayalam script is that they just identify the target graphemes without any underlying graphemic representations.

Apart from this, we still see a correlation of RT between both participant groups and TS Binary Letter Recognition tasks.

Our second question is the applicability of the two levels of orthographic knowledge when we move from one level of reading to the other, i.e., letters to words or words to sentences in a language. Automaticity in reading, by achieving automatic processing of subsequent components in a sentence, results in less reading time. This is seen in the case of sentence processing in the case of Malayalam participants. These participants were experts in TS or RS Malayalam, with their subsequent TS or RS sublexical knowledge levels. TS experts read TS sentences faster compared to RS sentences, and RS experts read RS sentences faster compared to TS sentences. There is a correlation between fluency in reading sentences and their subsequent sublexical orthographic knowledge levels (For a detailed description of results, refer to Chapter 4, section Results). Automaticity in reading theory proposes that the lower RTs of reading RS sentences entail lower RTs in reading the components in the sentence. This implies that components of the RS sentences, i.e., RS words and RS letters, would also be read faster by the experts with orthographic knowledge in RS. Contrary to this, with our results on the current follow-up letter recognition experiments, we see both the participant types (experts in RS/TS Malayalam and novices in RS/TS Malayalam) reading TS letters faster compared to RS letters reflected in their longer RTs for experiment 1 as compared to shorter RTs for experiment 2. From these results, we see that automaticity in reading cannot be generalised across the three levels of reading and automaticity in reading is highly level specific, i.e., automaticity at the sentence level is not the same at the letter level. The current study results show RS letters are hard to discriminate across group types compared to letters in TS. At the sentence level, higher automaticity for the RS experts could be due to a lower cognitive load on working memory. The experts would have a complex schema of TS sentences, leading to less retention time of input sentences in working memory. This creates a lower cognitive load for the experts in TS, leading to a fluent reading of TS sentences. This should have been the case with the components of TS sentences, i.e., the component of a TS sentence, which is the TS letter, should also create a lower cognitive load on the working memory, leading to fluent letter recognition. The contrasting results of letter recognition tasks point towards a separate schema or a separate orthographic knowledge base of TS sentences as well as TS letters.

Conclusion

The orthographic knowledge and its two levels should not be generalised to words and their component letters. The lexical and sublexical orthographic knowledge levels are formed separately for letters and words. This explains the performance difference in the processing of the same letters when they appear in isolation and in words and sentences. The concept of automaticity in reading theory, which suggests that quicker reading times for RS sentences are indicative of faster reading times for their individual components, such as RS words and RS letters. This implies that individuals with expertise in RS should read RS components faster. However, the results from a letter recognition experiment challenge this notion, as they reveal that both RS/TS Malayalam experts and novices in RS/TS Malayalam read TS letters faster compared to RS letters. In experiment 1, participants had longer reaction times (RTs), whereas in experiment 2, they had shorter RTs for TS letters. This suggests that automaticity in reading is not consistent across different levels of reading and is highly level specific.

The study results indicate that RS letters are challenging to discriminate, especially among different group types, compared to TS letters. At the sentence level, higher automaticity for RS experts is attributed to a lower cognitive load on working memory, possibly due to a more complex schema for TS sentences, resulting in reduced retention time of input sentences in working memory and fluent reading. However, this fluency does not extend to TS letters. The contrasting results suggest the presence of a distinct schema or orthographic knowledge base for TS sentences and TS letters, which is separate from that of RS.

Chapter 6.
Thesis Conclusion: Bringing It All Together

Introduction

The world we live in is replete with stimuli that interact continuously with our sensory perceptions. Due to the limited processing capacity and attentional resources, the brain, i.e. the decision-making organ, needs a mechanism to prioritise the stimuli. Attention, specifically the selective attention component of attention, is this mechanism, which this thesis aimed at exploring.

The field of selective attention is very vast and is explored using different methods and tools from behavioural, cognitive, and neurosciences. In this thesis, we limited our inquiry to only four main questions, the answers to which were established using literature review and behavioural methods of experimentation. These questions repeated from the first chapter of this thesis are:

What is load and selective attention as referred to in the field of cognitive sciences, especially the Perceptual Load Theory?

This is a conceptual question that led to exploring and collating the knowledge from the existing theories and relevant studies on selective attention. Accordingly, the first chapter attempts to conceptually capture the major theories in the field of selective attention and how load has been described and used as an experimental tool in relevant selective attention studies. With the help of studies pertaining to Perceptual Load Theory, chapter 1 explores the two most common and frequently used, yet subjectively defined, terms in the plethora of selective attention studies - Load and Task. We surmised that when an individual begins performing an assigned task, the processes of perception (capturing sensory information), cognition (acquiring knowledge), and retrieval (getting information from memory) associated with the task happen simultaneously, depending upon multiple parameters associated with the task itself as well as the individual themselves. To test these aspects of subjectivity, three parameters, which would be major factors in selective attention, were tested in three experiments. These experiments with their experimental research objective are as follows:

Does the modality of the task affect selective attention? How does selective attention function with different types of tasks, e.g., visual vs. auditory tasks?

The first experiment was designed to test the effect of the modality of the tasks on the task performers. The task was designed with cross-modal targets and distractors along with varying distractor congruency. Within our first experiment on the modality of the tasks and selective attention, we had three sub-parameters, namely, the modality of the target and distractors, the congruency of the distractors, and the load induced by the tasks. The results show that there indeed is an effect of modality on the response time and accuracy scores of the participants. Most of the earlier multimodal studies on attention had the targets and congruent distractors from the same modality, while the incongruent distractors from a different modality (Beck & Lavie, 2005; Hausfeld et al., 2021; Lavie & Cox, 1997). These studies have shown that congruent distractors interfere with the targets more than incongruent distractors.

Our first finding was based on analysing the effect of modality by having both the congruent and the incongruent distractors from a different modality than the target. The results show that, for the participants, the auditory distractors were more interfering while performing visual tasks with lower accuracy scores in tasks. In contrast, the visual distractors did not interfere much with the auditory task, resulting in their higher accuracy scores. This finding indicates that modality plays an important role while selectively attending to a particular target.

Our second finding was based on the effect of the distractors on the target. While performing a task, studies show that the distractors congruent to the target caused more interference as compared to the incongruent distractors (Nambiar & Bhargava, 2023). Previous studies also mostly looked at the effect of congruency using a single modality, i.e., where both targets and distractors were from the same modality. The present study employed targets and distractors from different modalities with different congruency ranges, in effect, better mimicking a real-world scenario. The results indicate that the incongruent auditory distractors were more distracting, as the RT taken by the participants for the visual task was much longer as compared to the auditory task. On the contrary, the RT for the congruent distractors in both modalities almost remained the same. This shows that the incongruent distractors to the target, irrespective of the modality, interfered with participants' selective attention and affected their performance. Our third result about the load induced by tasks and its effect on distractors contrasts the findings of previous research in the field of PLT (Dalton & Fraenkel, 2012; Macdonald & Lavie, 2011). PLT suggests that a higher load goes with lower distractor interference, and a lower load goes with higher distractor interference. In the present study, the subjective load measurement using the NASA TLX questionnaire indicated higher load scores for the visual task than the auditory task. The order of the task, i.e., whether the participant performed the auditory or the visual task first, impacted the performance. The participants reported a higher load in the visual task when it was performed after the auditory task. The higher load reported in the visual task, according to the past studies in PLT (Macdonald & Lavie, 2011; Molloy et al., 2018; Zäske et al., 2016), should have eliminated the interference of both congruent and incongruent auditory distractors on the visual task. However, it was affected by the distractors as compared to the low load marked auditory task, which showed lesser distractor interference. Contrary to the previous findings (Molloy, 2019; Molloy et al., 2020), which suggest that high-load tasks improved performance by effectively blocking distractors, the present study showed comparatively low performance in the high-load visual task compared to the low-load auditory task. Modality, therefore, should be considered as a significant parameter while designing tasks in PLT studies. The results explain why certain everyday visual tasks, such as driving, where accidents might be caused due to listening to phone conversations, are more auditory-distractor interference prone. The present study indicates how auditory distractors, especially incongruent distractors to the target, cause more interference while performing a visual task. The results also suggest the importance of subjective measurement of the load of tasks rather than the experimenter designating the load pre-performance of the participant. This allows us to understand the effect of modality on performance better rather than speculating only on load being the cause of performance differences among participants. The next two research objectives were as follows:

Does the nature of the task interact with selective attention? The nature of the task refers to whether the task was linguistic or non-linguistic.

and

Does the type of participant play a role in the management of load and attention? Do experts, compared with novices, use attention the same way?

These two objectives were explored in interrelated experiments where the findings of one experiment led to the formulation of the other. For objective 3, the experiment was designed to see how a change in script interacts with the orthographic knowledge of the users of the script. Here, we specifically looked at the linguistic nature of the target, its subsequent knowledge base, and its effect on selectively attending to tasks by measuring the performance scores of the participants. This was achieved by comparing the reading and writing measures of participants who had their elementary education in Traditional Script (TS) Malayalam (pre-reform, i.e. 55 years and above) with those who had their preliminary education in Reformed

Script (RS) Malayalam (post-reform, i.e. 54 years and below). Whereas the pre-reform group had ample exposure to TS, the post-reform group had exposure to mostly only RS. The experiment also incorporated the participant type and their effect on selective attention from objective 4. This helped to see whether, apart from the linguistic nature of the tasks (reading and writing tasks), the difference in the orthographic knowledge levels of participants affected their performance and whether it followed the results from the existing literature on participant type. We found that both groups were able to read both scripts, though with some differences in performance. It may be noted that though the reform was passed in 1971, the books and print media in TS that were in circulation before the reform were not banned and have continued to be in circulation even after the reform. Thus, print material in TS may have been in circulation alongside the material published in the RS. This might explain why even the younger people were able to read in TS, albeit slowly.

We had hypothesised that the lexical orthographic knowledge should primarily be composed of the script in which the participants had their elementary education, and this lexical orthographic knowledge would have an impact on script processing, i.e., reading. Based on this hypothesis, we expected that the pre-reform group participants would experience less processing demand when reading sentences in TS compared to RS, which should be reflected in shorter reading time (RT) for sentences in TS compared to RS. Similarly, the post-reform participants would experience more processing demand, reflect as longer RT while reading sentences in TS as compared to RS. However, against the expectation of the hypothesis, our results of the self-paced reading test show that the participants of both groups were faster in reading sentences in RS as compared to the sentences in TS. Although the elderly pre-reform group took longer time than the younger post-reform group, which could be explained on the basis of the general slowdown of the executive functions in the elderly participants (Kane & Engle, 2002; Logan, 1985), the difference between RS and TS persisted within both the groups.

The fact that both the groups read faster in RS indicates that there was less processing demand in reading words in RS script. One indication of this is that the lexical orthographic knowledge for both groups is largely composed of mental graphemic images of the words in RS, making the retrieval faster. This makes sense for the post-reform group who had received their elementary education in RS and not in TS. But for the pre-reform group, who had their education in TS, the reading results imply that either RS has completely replaced TS from the lexical orthographic knowledge, or more likely, RS co-exists with TS in lexical orthographic knowledge, and somehow RS has a significant presence, closer to retrieval. This could be true because reading is a skill that is practice-based and hence would be sensitive to exposure. Since the print media and educational textbooks changed the fonts to RS from TS after the reform order, the reading exposure must be in RS.

This is in contrast with most of the literature existing in load theory on expertise and novices (participant type - Objective 4). An additional or alternate explanation for the participants, regardless of their elementary education, reading faster in RS is that RS is inherently easier to read as compared with TS, resulting in lower processing demand and shorter reading times. The consonant-vowel and consonant-consonant clusters in TS form a unique glyph different from either of the constituent letters. The letters are written as separate entities in RS. Because of this, RS is likely to have lower complexity, making it easier to read as compared to TS. An indication of evidence comes from Liu et al. (2017), who found that the elderly have lower thresholds for crowding of the letters in reading tasks. This seems like a tenable explanation, which can be further strengthened through the tests of discriminability.

The writing task was provided to observe the interaction of the scripts with sublexical orthographic knowledge. The task of writing the dictated speech would have activated the rules connecting sounds to graphemes and the occurrence of graphemes in each other’s context, which is what sublexical orthographic knowledge deals with. The participants were asked to write the dictated sentences but were not overtly asked to pick any script. It was expected that when asked to produce written material, participants would use the script they had learnt in their elementary education, *viz*., the pre-reform participants would write in TS, and the post-reform participants would write in RS. Following the expectation, we found a clear relationship between the group type and the kind of glyphs written. The pre-reform group wrote primarily using the TS glyphs, whereas the post-reform group wrote primarily using the RS glyphs. This confirms that sublexical knowledge is indeed formed with the script one learns in elementary education. This is further confirmed by the correlation results. For the pre-reform group, there is an inverse correlation with RS glyphs and a positive correlation with TS glyphs. This implies that the group type uses sublexical knowledge of the script in which they had elementary education to write in a dictation task.

This shows that a conscious effort and practice may help a person override the script acquired through their elementary education and thus reorganise their sublexical orthographic knowledge at a personal level. One would expect both the lexical and sublexical orthographic knowledge to be composed of the same script. This does seem to be the case with the post-reform group. However, with the pre-reform group, the reading results indicate the lexical orthographic knowledge to be composed largely of RS. In contrast, the writing results indicate the sublexical orthographic knowledge to be composed largely of TS. This difference in the reading and writing results in the pre-reform group is a strong indicator that orthographic knowledge indeed has two independent and separate levels. The sublexical orthographic knowledge from the results seems to be more rigid than lexical orthographic knowledge as it does not update with years of exposure, as seen with the pre-reform group participants. This also implies that reading and writing function differently in the case of scripts, and like orthographic knowledge, should be tested at two levels each in the case of lexical and sublexical knowledge.

The existing consensus of lexical and sublexical orthographic perspectives are mostly Anglo-centric in nature, with analyses mostly with Roman script or European alphabets. The current study, therefore, is a step towards bringing universality in the claim of the existence of the levels of orthographic knowledge using a lesser-studied script from the Indian subcontinent.

The results of this follow-up study on letter recognition as part of the broader reading fluency and orthographic knowledge levels confirm the existence of two levels of orthographic knowledge bases but separate for the three levels of reading. Having lexical and sublexical levels of orthographic knowledge for a particular script does not entail that the levels of knowledge are rigid and the same for all its levels of reading, namely letters, words and sentences. The differences in performance for the same participant across reading levels in a given script with the exact same graphemes used in letters, words and sentences establish the possibility of multi-layered separate orthographic knowledge levels. This difference in performance in letter recognition could be more perceptual and extrinsic in nature than intrinsic. If it were not extrinsic in nature, we would have seen no difference in performance between the participant types, with Type 1 being experts in Malayalam scripts and the latter with no knowledge of the chosen script.

Beyond the predictable differences in performances of participant types, we see a significant effect on RTs and accuracy scores across the participant types. Irrespective of the participant types, both groups took a longer duration in Task 1 -- match-mismatch binary decision task in RS script. The accuracy scores, too, were lower for Task 1, irrespective of participant type.

Our first question is whether fluency stays uniform in three levels of reading when the same graphemes are used across levels for Groups 1 and 2 participants. One limitation we have here is that for participants from Group 2 who are novices in Malayalam script, calling the two experiments reading tasks would be problematic. Here, in the tasks, they are just identifying the target graphemes without any underlying graphemic representations. Apart from this, we still see a correlation of RT between both participant groups and TS Binary Letter Recognition tasks. Irrespective of the expertise and exposure of Group 1 participants, the RT scores for the RS Binary letter recognition task. The same trend was seen with Group 2 participants. This possible explanation here is that letter-level identification usually does not happen like word recognition or context comprehension tasks. Here, the letters in isolation, in fact, are broken down into features by the participants to differentiate one grapheme from the other. The moment the features are discriminated for recognition, we have to consider the perceptual space taken by the grapheme. If the grapheme is crowded feature-wise, we can assume that it creates perceptual graphemic load or 'Scriptual Load' for the participants. Thus, here in the study, as the RS graphemes take perceptually more space and processing it linearly would take more attentional resources, we can conclude that RS graphemes create scriptural load for the readers, hence the longer RTs.

Our second question is the applicability of the two levels of orthographic knowledge when we move from one level of reading to the other, i.e., letters to words or words to sentences in a language. Automaticity in reading, by achieving automatic processing of subsequent features in a sentence, results in less reading time. This is seen in the case of sentences, but with our results in letter recognition tasks in two experiments, we know that automaticity is not level generic in terms of reading but level specific. What is automaticity at the sentence level isn't the same at the letter level. We have found a discrepancy in this study as compared to the preliminary one (Nambiar et al., 2023) where in the previous study, automaticity made RS sentences easier to read for the Malayalam speakers, but the current study results show RS letters are hard to discriminate across group types when compared to letters in TS.

The orthographic knowledge and its two levels should not be generalised to words and their component letters. The lexical and sublexical orthographic knowledge levels are formed separately for letters and words. This explains the performance difference in the processing of the same letters when they appear in isolation and in the form of meaningful words. Letters being a meaningful unit to the Malayalam speakers and just a non-meaningful shape to the non-Malayalam speakers – explains how words as a whole are processed differently. TS is more discriminable at the letter level across participant groups. The fluency we see at the letter level is not visible in the word-by-word sentence processing level. At the higher reading level, which is word and sentence level, TS takes more RT and less accuracy across participants (Nambiar et al., 2023). The fluency is not reading levels dependent, and there is no hierarchy between levels. Another possible reason for the similar performance of Group 1 and 2 participants on the RS Binary Decision Task is that at the letter component level, the letters function more as image stimuli than linguistic stimuli. This is evident from the group 2 participants' performance. They were able to discriminate TS better than RS, similar to the performance of group 1 participants.

Orthographic knowledge functions differently at the different levels of reading across different participant groups. A person's reading fluency is therefore governed by the two levels of orthographic knowledge (Apel et al., 2019); mental representations of words or word parts and the rules or patterns of representing a sound in the form of letter or word forms.

Specific Contributions

The thesis examines the less explored parameters of selective attention and its possible impacts on the task performance of human beings. Most of the studies on selective attention have tasks designed with either targets or distractors from the same modality. The results from these studies are then assumed to be applicable to the entire domain of selective attention. We have made an attempt to address the assumption by expanding the parameters. We did this by including subjective aspects of how selective attention might get affected and reflected in their performance.

We see from our results that the modality of the targets and distractors and their congruency with each other in an assigned task interferes with the performance of the individuals. Our findings imply that the congruency between distractors and targets has an impact on selective attention and the perceptual load involved in tasks. Interestingly, it appears that auditory distractors in visual tasks create a higher subjective load compared to visual distractors in auditory tasks. Previous research in Perceptual Load Theory suggested that under high task load, neither the type nor the congruence of distractors would influence participants' performance.

Contrary to this belief, our findings demonstrate that even in high-load situations, congruence plays a role in shaping selective attention. This suggests that when designing tasks to study selective attention, the influence of modality needs to be taken into account. Our results underscore the significance of modality, indicating that it holds a similar weight to task load in affecting selective attention. Moving forward, it is essential to conduct more extensive studies involving participants from diverse backgrounds to explore the impact of additional factors, such as culture, gender, and socioeconomic status, in order to obtain more comprehensive results.

In the case of attentional resources allocated for literacy in a particular language, one might anticipate that both lexical and sublexical orthographic knowledge of an individual would be in a script that they had their elementary education in. This pattern appears true for the post-reform group of Malayalam speakers, where both lexical and sublexical orthographic knowledge align with the RS of Malayalam. However, in the pre-reform group of Malayalam speakers, the reading results suggest that lexical orthographic knowledge is largely RS. In contrast, the writing results indicate that sublexical orthographic knowledge is predominantly TS. The disparity between reading and writing results in the pre-reform group strongly indicates that orthographic knowledge indeed has distinct and separate levels. The results imply that sublexical orthographic knowledge is more resistant to change than lexical orthographic knowledge, as it does not adapt with years of exposure, as observed in the pre-reform group participants. This also suggests that reading and writing function differently in the context of scripts. Therefore, researchers and scientists conducting tests in language on selective attentional resources should consider testing both lexical and sublexical knowledge separately for reading and writing tasks in the case of scripts.

The concept of automaticity in reading, which involves the ability to process subsequent elements in a sentence automatically, proposes to reduce reading time. While this effect is observed in sentences, our findings in two experiments on letter recognition tasks suggest that automaticity isn't universally applicable across all levels of reading; it varies according to the specific level and does not depend on the expertise of the participant in a given script. In other words, what constitutes automaticity at the sentence level is not the same as at the letter level. This study reveals a discrepancy compared to our previous research, where automaticity facilitated the reading of RS sentences for Malayalam speakers. However, in our current study, we found that RS letters are challenging to differentiate across different participant groups irrespective of expertise when compared to letters in TS.

Orthographic knowledge, along with its two distinct levels, should not be generalised to encompass words and their constituent letters. The two levels of orthographic knowledge, lexical and sublexical, are separately developed for letters and words. This disparity explains the differences in performance when processing the same letters in isolation versus within meaningful words. While letters hold significance for Malayalam speakers, they are merely abstract shapes for non-Malayalam speakers. The fluency observed at the letter level does not extend to processing words and sentences.

Orthographic knowledge operates differently at various reading levels across diverse participant groups. A person's reading fluency is influenced by two levels of orthographic knowledge: mental representations of words or word components and the rules or patterns governing the representation of sounds in the form of letters or words.

Limitations

Selective attention research is valuable for understanding how individuals process information on a daily basis. However, the research in this field faces certain criticisms in general, which are also applicable to the studies reported in this thesis. For example,

- Behavioural experiments, e.g. the first experiment reported in the thesis, are conducted in a controlled laboratory setting.
- Further, the tasks used to study selective attention are often simplified versions of real-life activities.
- The presence of the experimenter may introduce a potential bias in attention.
- It is nearly impossible to accurately represent the vast real-world demographics of the participants used in these studies.
- At least some parameters are measured through post-experiment questionnaires, which may not accurately capture the real-time dynamics of attention processes.
- Selective attention itself relies on indirect measures such as reaction times or error rates.
- Each experiment cherry-picks tasks, stimuli, and contexts for certain experimental objectives. This impedes the unrestricted applicability of the results obtained in one experiment to other experiments that involve other types of tasks, stimuli, and contexts.

Because of the aforementioned factors, not only may the settings not accurately capture the complexities of real-world situations, but the behaviour of participants and their experiences may themselves be qualitatively and quantitatively different from real life, making the experimental results less applicable to the larger population and in real-world situations.

Further, these studies can establish correlations between variables but often struggle to establish causation. It may be challenging to determine whether a particular manipulation directly causes changes in selective attention.

The criticisms mentioned here are commonly faced by laboratory-based experimental studies in Psychology. In fact, if the study parameters are not standardised, simplified, and tested in a controlled environment, it would be impossible to take into account all the confounding factors that play any role in real-life situations, making it impractical to conduct a study in the first place. Depending on the objectives and design of the study, some parameters need to be incorporated or ignored, for example. This is called the scope of the research. Laboratory-based experiments should not be considered to be the replacement of real-life situations but merely the tools to receive a glimpse into interesting phenomena and effects that stand despite simplifying the protocols.

Despite the stated drawbacks and weaknesses, selective attention studies are essential for advancing our understanding of how attention functions and generating insights that can inform various fields, including psychology, education, and marketing.

Scope for Future Research

What we learn about selective attention in laboratory-based studies can enhance our understanding of how selective attention works and fails in everyday situations. One such situation is where distractors impair our ability to focus on critical information while driving. For example, using a mobile phone while driving diverts attention from the road, increasing the risk of accidents. Results from behavioural studies like this one can inform whether auditory distractors from hands-free calling systems and on-board music systems, and visual distractors from roadside hoardings, or a combination of both, shall be more disruptive to the attention of a driver.

Our results suggest that reading and writing tasks are attempted differently by participants, and their expertise in orthographic knowledge in the script in which they were doing the reading and writing tasks did not have an effect on their selective attention performance scores as compared to the other participants who were novices in terms of orthographic knowledge. Further studies can be carried out, incorporating learners from different age groups and backgrounds, such as classroom learners, bilingual learners, young adults and others, to see how selective attention functions in contexts of various participant types. The linguistic task in the current research is limited to Malayalam orthography. This can be further broadened in future research by incorporating other Brahmi-derived scripts to assess their impact on orthographic knowledge and task performance of individuals. The current study has specifically focused on letter-level and sentence-level reading, it could be further expanded by incorporating other linguistic aspects such as syntax, semantics and pragmatics of a particular language and its possible effects on the selective attention of individuals.

In a classroom setup, teachers and educators can be aware of the effect of perceptual and cognitive load on the selective attention of students while designing engaging lessons that capture students' focus with fewer distractor interferences. Developing curriculum and modules for the students can consider incorporating strategies to reduce both perceptual and cognitive load involved in tasks based on student type and task type (linguistic/non-linguistic; modalities involved). This would aid in maintaining students' attention and facilitating learning.

For developing a user interface in computer programs, designers rely on selective attention research results to create intuitive as well as easy-to-access interfaces. These programmes are then implemented in real-life scenarios such as Air Traffic Controlling. From our results, we see that the parameters such as incongruent auditory distractors deviate users' attention while performing a visual task. User interface advancements studies for Air Traffic Controllers can ensure that essential information and suggestions are prominently or subtly displayed on their visual display, so that optimal perceptual load is experienced by them in processing and accurate reporting of the aircraft traffic. A higher perceptual load created by visual signals should be avoided while programming the interface in future to avoid inattentional deafness faced by pilots and other controllers, leading to missing essential/deviant signals when the visual perceptual load is high on the display.

In healthcare settings, understanding how selective attention operates can aid in better designs of alarms and systems. Alarms are known to cause cognitive fatigue in medical aid workers (Lewandowska et al., 2020). In order to design better alarm and warning systems in critical-care medical equipment, one needs to take into account the perceptual load induced by the visual versus auditory warnings. This may be the difference between proper care and negligence- and fatigue-induced mistakes. Another field that may benefit from the findings of the study is the area of printing and reading. The studies reported in the thesis indicate that the exposure to the script and font one receives at childhood, stays forever. However, reading speed (and ease) are trainable, and can be updated even at a later stage in life, possibly through exposure to fonts and scripts. What remains to be seen is, if the results found with Malayalam script would be replicable with other scripts from Indian languages. Even though many Indian scripts are derived from the Brahmi script, the modern scripts have veered away from each other due to several historic, social, and cultural factors. Thus, it appears that the observation made with Malayalam script may or may not be replicable for other scripts. This is a study that may be taken up in the future.

Behavioural studies have shown that our attentional resources are limited in nature, hence, multitasking can be less efficient, and people may be less productive when they switch between tasks (Cain et al., 2013; Chinchanachokchai et al., 2021; Merz et al., 2021). Understanding this helps individuals and organisations to manage workloads better and improve productivity by minimising risk of failures due to task-switching. Being aware that someone is actively listening and providing focused attention, is key to effective interpersonal interactions.

Thus, it is hoped that the knowledge accrued through the studies reported in this thesis can be applied to various fields to improve communication, decision-making, and overall human performance, while minimizing risk of making errors.

Through this research, I would also like to emphasise the importance of non-invasive behavioural studies in the field of selective attention. These studies are easy and cost-efficient to run compared to invasive neuro-cognitive studies and help us understand how attention operates in everyday situations without altering or interfering with the natural behaviour of individuals. For future and further research on various stands of selective attention, this knowledge is crucial for establishing a baseline of what constitutes typical attentional functioning. While behavioural studies do not directly measure brain activity, they provide essential data that can complement neuroscientific research, such as neuroimaging or electrophysiological tests. Conducting behavioural non-invasive studies on selective attention respects ethical considerations by not subjecting individuals to potentially harmful or invasive procedures. Overall, the studies on selective attention reported in this thesis help us better understand how individuals process and filter information in everyday life.

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List of Publications

1. P. Bhargava and K. Nambiar, "Bibliotherapy with Context: Interpreting the Symptoms of Disability in 'Flowers for Algernon,'" *North American Journal of Psychology*, vol. 25, pp. 151–160, Jan. 2023

2. K. Nambiar and P. Bhargava, "An Exploration of the Effects of Cross-Modal Tasks on Selective Attention," *Behavioral Sciences*, vol. 13, p. 51, Jan. 2023, https://doi.org/10.3390/bs13010051

3. K. Nambiar, K. Kishore, and P. Bhargava, "The effect of script reform on levels of orthographic knowledge: Evidence from Alphasyllabary Malayalam scripts," *PLOS ONE*, vol. 18, no. 8, p. e0285781, Aug. 2023, https://doi.org/10.1371/journal.pone.0285781

List of Conference Presentations

- Presented paper on 'Effect of Cognitive Factors on Second-Language Learning: Achievement Motivation and ADHD learners' at ELT Summit 2020 virtual international conference by International Society for Educational Leadership (ISEL) and ELT @ Pune Chapter (June 27-28, 2020)
- Presented paper on 'Accuracy in Reporting Clinical Tests in Texts with Disability: Analyses of 'Flowers for Algernon' and 'My Name is Brain Brian' at Virtual International Conference English Literature Summit 2020 by International Society for Educational Leadership (ISEL) (December 12-13, 2020) Books & Proceedings (isel.education)
- Presented poster on 'An Exploration of the Effects of Bimodal Stimuli on Selective Attention' at ACCS8: 8th Annual Conference of Cognitive Science by Association of Cognitive Science, Government of India and Amrita Mind Brain Center, Amrita Vishwa Vidyapeetham (January 20-22, 2022) ACCS8 Proceedings Book (amrita.edu)
- Presented paper on 'A Case of Script Alienation Amongst Elderly Malayalam Speakers' at Oral History Association of India (OHAI) 8th Annual Conference IIIT, Hyderabad (March 10-12, 2023)
- Presented paper on "The Effect of Script Reform on Levels of Orthographic Knowledge: Evidence from Alphasyllabary Malayalam Scripts," at the 30th annual International Meeting of the Society for the Scientific Study of Reading (SSSR), Port Douglas, Australia (July 19, 2023)

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