

**INFLUENCE OF LANGUAGE ON MIXED AND SEPARATE BLOCK STROOP  
TASK PERFORMANCE**



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## CERTIFICATE

This is to certify that the thesis entitled, 'Influence of Language on Mixed and Separate Block Stroop Task Performance' is being submitted in partial fulfilment of requirements for the award of the degree of Master of Arts in Psychology, presented in the Thapar School of Liberal Arts & Sciences, Thapar Institute of Engineering and Technology, Patiala is a bonafide work carried out under the supervision of Dr. Anuj Shukla, Professor, Thapar School of Liberal Arts & Sciences, Thapar Institute of Engineering and Technology, Patiala and that no part of this project has been submitted for the award of any other degree.



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



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## CANDIDATE'S DECLARATION

I hereby declare that the work presented in this thesis entitled, 'Influence of Language on Mixed and Separate Block Stroop Task Performance' submitted in partial fulfilment of requirements for the award the of the degree of Master of Arts in Psychology, presented in the Thapar School of Liberal Arts & Sciences, Thapar Institute of Engineering and Technology, Patiala, is an authentic record of my work carried out under the supervision and guidance of Dr. Anuj Shukla, Professor, Thapar School of Liberal Arts & Sciences, Thapar Institute of Engineering and Technology, Patiala and refers other researchers' work which are duly listed in the reference section.

The matter embodied in this thesis has not formed the basis for awarding any other degree at this or any other university.

Date- May 15, 2023

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## **Abstract**

Automaticity is often linked to proficient performance. Automatic processes are typically perceived as beyond conscious control, implying a lack of volitional regulation. The Stroop color-naming test serves as a prominent illustration of automatic word reading and its uncontrollable nature. The Stroop task is also widely used to explore the structure of bilingual lexicons. The present thesis uses two different variants of Word-Colour Stroop Task to study the influence of language on the Stroop task performance. In the first study, we presented Hindi-English mixed Stroop with congruent and incongruent colour condition; whereas the second study had separate blocks for each language. The results indicated a significant Stroop effect in the English language (L1), but not in Hindi (L2), for both experiments. In experiment 1, participants exhibited greater Stroop interference in the English-incongruent condition compared to the Hindi-incongruent condition, while the interference was lower in the English-congruent condition compared to the Hindi-congruent condition. In experiment 2, a notable group effect was observed, indicating that participants took longer to respond in Hindi than in English for both congruent and incongruent conditions. This demonstrated a general delay in responding to the Hindi trials, regardless of the condition. Based on these findings, it is proposed that tests, particularly those assessing cognitive abilities, should be conducted in participants' native language to enhance the accuracy and reproducibility of results. These insights may hold significant clinical implications, particularly considering the scarcity of Hindi-English mixed Stroop Task research in India.

## **CHAPTER – 1**

### **INTRODUCTION**

Stroop Task is one of the most widely used neuropsychological tests to study executive control, attentional control and language proficiency (Tzelgov, Henik, Leiser, 1990; Gerhand, DerCgowski, McAllister, 1995; Lee, Chan, 2000; Roselli, Ardila et al., 2002). Along with these research domains, bilingualism has been of great interest to cognitive psychologists. The first to use Stroop task on bilinguals was Dalrymple-Alford (1968), followed by Preston & Lambert (1969) and Dyer (1971). The Stroop task requires participants to name ink colours of printed colour words that are incongruent (e.g., blue written in green ink, the expected correct response is green) and words that are congruent (e.g., blue written in blue ink, the expected correct response is blue). There is a delay in colour naming evoked in the incongruent condition, this delay is referred to as the Stroop effect or interference effect (Stroop, 1935). This refers to the increase in the reaction time in the incongruent condition as compared to the neutral condition (e.g., coloured Xs) and congruent condition. It is mentally challenging for anyone to ignore the meaning of the word and focus on the colour ink in which the word is printed. The capacity of the individual to avoid an automated response (i.e., reading the colour words) as opposite to the unusual response (i.e., naming the colour ink of the word) is assumed to be the efficiency of attentional control in the colour-word Stroop task (Macleod, 1991). Due to its simplicity and the imbalance between the stimulus's many dimensions, this variant of the Stroop task (i.e., colour – word) has some limitations. First, each trial in the color-word Stroop test only has one stimulus. Throughout our daily lives, we come across complicated settings that contain multiple stimuli at once. Second, there is typically no congruency effect when participants are instructed to read the word and ignore the colour in the color-word Stroop task because reading is significantly more automatic than naming the colour (Stroop, 1935).

## 1.1 Various Types of Stroop Tasks

These days, there are various Stroop test variants depending on the number of stimuli, the length of the task, the number of tasks and subtasks in the test, and the scoring method. The Stroop effect is not only responsible for the interference between colour and word processing; it is also the cause of other types of interference, including: a) word processing and the picture, where a conflicting word is integrated in a picture and naming the picture causes interference from the word, but reading the word is hardly influenced by the picture; b) word processing and the direction, where reading the word is once again unaffected by the mismatched arrow but there is some interference from the meaning of the integrated word when recognising the direction of the arrow; and c) the digit and numerosity processing, where counting the number of digits is hampered by the digits' incompatibility with their numerosity; d) and the Flanker task where the flankers, which occasionally also act as focal targets, make it difficult to identify the central letter (relative to flankers that are never targets) (MacLeod, 2015).

One can experiment with the Stroop task to see how emotional triggers affect people's ability to name colours. The *emotional Stroop task* (EST) is identical to the classic Stroop task but changes the semantic content of the word: on some trials, the word has a neutral connotation (for instance, "sketch") whereas on other trials, it carries a threatening valence (for instance, "assault"). So, by varying the emotional content of the word to be ignored and monitoring for any changes in performance, the EST can identify the impact of emotional processes on the typically cognitively oriented activity. Several studies show that nervous people, including those with post-traumatic stress disorder (PTSD) (Buckley et al., 2000; Foa et al., 1991; McNally, 1990) take longer to name colours for emotional words than for neutral terms (Bar-Haim et al., 2007; Williams et al., 1996). The degree to which the mechanisms underlying the emotional Stroop task are comprehended will determine the extent to which data from emotional Stroop studies contribute to a better understanding of the mechanisms causing

PTSD. Thus, it is crucial to understand the mechanics underlying the traditional and emotional Stroop test before making any specific conclusions. These mechanisms include, first, the enhanced EST effect in randomised designs (i.e., where neutral and threatening trials are randomly intermixed) found only among high-trait anxious people could be explained by a highly elevated threat detection mechanism that results in a greater "bottom-up" disrupting influence in response to emotionally arousing stimuli (cf., Bar-Haim et al., 2007). This threat detection system is in alignment with the theories put out by Williams and colleagues (1996) and Wyble and colleagues (2008) that anxious people have elevated output tendencies that are linked to emotional stimuli. Second, the extent to which emotional cues divert attention from task demands (Eysenck et al., 2007; Reinholdt-Dunne et al., 2009; Wyble et al., 2008) may be modulated by an attentional control mechanism that is in charge of orienting, maintaining, and shifting attention (cf. Posner, 1980; 1990). Both the delayed EST impact seen by McKenna and Sharma (2004) and the heightened EST effect in blocked design studies (i.e., when neutral trials all take place at once, then threatening trials all take place at once) might be explained by disruption of this mechanism (Bar-Haim et al., 2007). Together, these two mechanisms account for the diversionary effects of emotional stimuli, the enhanced EST effect in randomised Stroop formats among high anxious individuals, the enhanced EST effect in blocked designs across all individuals, and the exaggerated delayed EST effect discovered among high anxious individuals. These two mechanisms agree with all of the earlier explanations for the EST effect (Algom et al., 2004; Williams et al., 1996; Wyble et al., 2008). When the emotional Stroop task was administered to participants who were depressed, it was discovered that they required a disproportionately longer amount of time to report the colours of the depressing words than the colours of the non-depressing terms. Even with non-clinical participants, the test still required more time to describe the colour of emotional words than it did to report the colour of neutral terms. This might occur as a result of the word's emotional resonance with the subject.

For a more accurate examination of people's emotions, the researchers carefully choose the negative or emotional words to use in the emotional Stroop test (Larsen et al., 2006). A study was conducted by Ovaysikia et al., (2011) where emotional words and emotional faces were used in the Stroop experiment and it was discovered that words were processed more quickly than facial expressions, with incongruent trials resulting in slower reaction times and more errors than congruent trials. This could also be explained by the difference between awareness and selective attention, which would suggest that over-learned behaviours build stronger stimulus-response associations than instinctual ones. Williams et al., (1996) conducted a study in which the task required them to name the colours in which the stimuli word was presented and the words' applicability to each psychopathology-related issue varies. The authors examine data that demonstrates that patients frequently take longer to name the colour of a word when it is connected to issues important to their clinical state.

A different experiment was done to determine the relationship between *numerosity and duration*, as opposed to the conventional Stroop effect experiment that examined the relationship between word and colour processing. In this experiment, the subjects were presented "two series of dots in succession" and given the choice of answering either of the following two questions: a) Which series out of the two contains more dots? Which series appears to be lengthier from the first to the last dot of the series? Congruent stimuli refer to the condition where more dots lead to a longer series and incongruent stimuli refer to the situation where a few dots were flashed longer on the screen. The experiment's findings demonstrate the interaction between numerosity processing and duration, i.e. when the few dots were exhibited for a longer period of time, it was challenging for the subjects to choose which series appeared longer on the screen (Dormal & Pesenti, 2007).

The link between numerical values and physical sizes is illustrated by the *numerical Stroop effect* given by Henik & Tzelgov (1982), which is related to the normal Stroop effect. Regardless of their real values, digits might appear physically huge or little when they are displayed visually. Large “7” (**7**) small “5” (**5**) are examples of congruent pairs, whereas incongruent pairs occur when size and magnitude are mismatched (e.g., large “5” (**5**) small “7” (**7**)). The numerical Stroop effect is the difference in reaction times between congruent and incongruent pairs (or the size incongruity effect; SICE). A physical or a numerical size judgement task is performed by participants in separate blocks during a numerical Stroop trial. Participants in the numerical task ignore the physical sizes and respond to the values, whereas those in the physical task ignore the values and respond to the actual sizes. Neutral pairs can also be included in the main task. The two digits in neutral pairs only differ in one dimension (e.g., the pair “7” “5” for the numerical task and large “5” small “5” for the physical task). Neutral pairs make it possible to measure facilitation (i.e., the difference in response time between neutral and congruent pairs) and interference (i.e., the difference in response time between incongruent and neutral pairs). A working memory variant of the numerical Stroop problem was created by Wang in 2021. The participants had to commit a number to memory for a period. They were then instructed to choose which number was numerically or physically larger when the other number appeared.

## **1.2 Factors influencing Stroop performance**

Research has demonstrated a difference in the performance of bilinguals on Stroop tasks (Datta, Nebhinani & Dixit, 2019). However, within-language interference is frequently higher (Magiste, 1984). According to research, the degree of interference with both the Stroop task in bilinguals is also dependent on the level of language proficiency and the similarity between the two languages. Bilinguals store multiple languages in different mental dictionaries,

explaining the differences between monolinguals and bilinguals (Brauer, 1998). Language proficiency, often known as linguistic proficiency, refers to a person's ability to communicate or perform in a second language. The *language proficiency hypothesis (LPH)* given by Mägiste (1984). According to LPH, if the bilingual Stroop color-naming task is in the dominant language, it should create more interference effect than in the less proficient language. The interference produced by two language systems is equalised when subjects are balanced bilinguals. Past studies utilising proficient bilinguals have suggested that when a person is just communicating in one language, both languages are active at the same time (Blumenfeld & Marian, 2007; de Groot et al., 2000; Kerkhofs et al., 2006; Kousaie & Phillips 2012; Libben and Titone 2009; Paulmann et al. 2006; van Heuven et al. 2008). Furthermore, people perform better in their native language to minimise within-language interference, but not in a low-proficient language (Tzelgov et al., 1990). It has been suggested that the proficiency level of two languages of bilingual influences the amount of inhibition to the non-target language: the greater the difference in proficiency, the weaker the interference effect ('Costa's et al., 2006).

Apart from language proficiency, another factor that plays a role in influencing the performance of Stroop task can be executive control. Executive control is the capability of an individual to inhibit interference and focus on the goal (Gray et al., 2003). Bilinguals need executive control to reduce interference from non-target language and focus on the target language when using two languages simultaneously. Sometimes, while managing two language systems (first and second language) there exists a conflict in selection. Therefore, bilinguals continuously need to focus on the target language, called goal maintenance. For this, there is also a need for bilinguals to resist the non-target language; this is called conflict resolution. Studies suggest that bilinguals have an advantage in goal maintenance and conflict resolution (Abutalebi & Green 2007; Bialystok 2008; Costa et al. 2006). Interference in a Stroop task happens when the automaticity of reading prolongs the time it takes to focus on the

colour and produce a response. From a fundamental perceptual standpoint, Melara and Algom in 2003 suggested that two elements—dimensional imbalance and dimensional uncertainty—are responsible for Stroop interference. Dimensional imbalance affects how connected and unexpected a stimulus' two dimensions are, as well as how simple it is to recall a stimulus' representation from memory. Dimensional uncertainty measures the salience of a stimulus, specifically its likelihood or improbability in relation to other (recently presented) stimuli. By concentrating on salient, unexpected, and/or connected information within each dimension and between the two dimensions of a Stroop stimulus, these two elements work together to determine the effectiveness of attentional selection. Each has an impact on the suppression of distractions and the excitement of objectives. Stroop interference happens because the words are more salient than the colours and there is more uncertainty in the words than there is in the colours. In contrast, Stroop Facilitation occurs when the stimuli are presented in a congruent manner, such as the word 'GREEN' written in green ink, and there is no conflict (Van Heuven et al., 2011). Conflict resolution procedures and cognitive control, skills currently used by bilinguals to make linguistic choices, are necessary to overcome the mismatch between ink colour and word written (Van Heuven et al., 2011). According to Yu & Schwieter (2018), Bilingual advantages could be related to conflict management and resolution when both languages are used. Other studies have observed improved executive functioning, task switching, faster reaction times, inhibitory control, monitoring, superior flexibility, better career possibilities, and respect for cultures other than one's own are all positives (Donnelly et al., 2019; Gunnerud et al., 2020; Hartanto & Yang, 2019; Stasenko et al., 2017). Furthermore, Mechelli et al. (2004) reported that second language learning increases the density of grey matter in a specific region of the brain (the left inferior parietal cortex) and causes structural reorganisation to the degree that is modulated by the proficiency attained and the age at which the second language is acquired. The various theories that explain the Stroop task are: (a)

Automaticity is defined as the lack of attentional control while performing a cognitive activity (Kahneman, 1973). It is effortless because it requires less mental resources and happens automatically, therefore, it cannot be completely stamped out. 'The first law of bilingualism is that the two languages compete,' according to Traxler (2012: 419). It is necessary to choose an appropriate linguistic phrase (Bailystok et al., 2004). For example, when English-Hindi-speaking bilinguals hear the words 'red' and 'लाल,' they automatically activate both words; (b)

According to the "Selective Attention Theory," it takes more awareness and focus to recognise colours than to recognise words. To recognise a colour requires more brain activity than it does to read a text, which takes far longer (Treisman, 1964); (c) The theory of parallel distributed processing or connectionist model given by Cohen et al., (1990), holds that as we analyse the data, our brain creates a unique and tailored pathway for each task. Because some pathways—like reading—are more powerful than others—like naming colors—it is crucial to consider a pathway's strength relative to its speed. The stronger pathways, like reading a word, and the weaker pathways, like naming the colour, interact when the two pathways become active at the same time during the Stroop effect; (d) The theory of processing speed states that the brain finds it easier to read words than it does to recognise the colour of the word being presented, hence it takes more time to do so. It is based on the phenomenon known as the Stroop effect, which states that when naming colours and words clash, processing colours takes noticeably longer than processing words. Confusion results from the word information entering the decision-making stage before the colour information if the subject is required to report the word's colour. The word information enters before the colour information at the decision-making stage, but, if the subject is required to report the word (colour name), allowing the subject to respond in less time because there is no confusion. Another name for this theory is The Relative Speed of Processing Theory. Klein (1964) aimed to determine what features of the words made naming colours difficult. He added numerous new conditions in order to do

this. There were six interference cards along with the baseline "colors-alone" card. The standard incongruent condition, which involves employing words that contrast with the print colours, displayed significant interference as usual. Interference was cut in half when colour terms other than the names of the print colours were used, indicating a significant function for response set in interference. Interference subsequently decreased more gradually for words with a colour association (such as lemon and sky), for common, unrelated words (such as put and heart), for uncommon terms (such as sol and abjure), and finally for words with unpronounceable nonsense syllables (e.g., hjh, gsxrq). Apparently, despite being told to disregard the word, individuals are unable to do so, and the more relevant the word, the more interference it causes with colour naming.

### **1.3 Role of Language in Stroop**

It has been found that bilinguals outperform monolinguals across age groups including children and older adults on various linguistic and non-linguistic tasks that require executive control such as the Simon task (Bialystok et al., 2005), Flanker task (Costa., 2006), Go/No-Go task (Rodriguez-Fornells A et al., 2005), Stroop task (Bialystok E et al., 2008) ANT Attention Network Task (Costa et al., 2006). There are various factors that have association with bilingualism that interact with executive control mechanisms (Singh & Mishra, 2012) such as age of language acquisition (Luk G et al., 2011) and level of proficiency of second language. As there is an increase in the proficiency of the second language, there is a decrease in the dependence on the first language and therefore subjects tend to reply to amodal concepts in their semantic selection (Tzelgov, Henik, Leiser, 1990). It has been reported by various researchers that cognitive control advantage in Hindi-English bilinguals is due to the second language proficiency (Singh & Mishra 2012; Singh & Mishra 2013; Kar and colleagues, 2011; & Khare and Colleagues 2013). The outcomes of a study conducted by James et al., (2018) propose that second language words impact semantic and response processing in

basically the same manner to first language words, as opposed to having reduced semantic or potentially response impacts. It has been found that contrasted with non-proficient bilinguals, proficient bilinguals showed better cognitive control at repressing superfluous data, and they were slower at naming the shade of the English words (Wang et al., 2016). The results of a study conducted by Pathak & Pathak (2022) show that high proficient bilinguals show the bilingual advantage in language comprehension, language production and executive control tasks. High and low proficient Hindi-English speaking bilingual groups did not differ with regard to the interference effect observed (Singh & Mishra, 2015). Proficient bilinguals showed less Stroop interference than non-proficient bilinguals in Chinese but not in English (Wang et al., 2016).

Recently, there has been an increase in the literature that provides information against the bilingual advantage of cognitive control over monolinguals, and there has also been a low level of convergent validity across non-linguistic, control tasks and the size of the sample among bilinguals and monolinguals (Paap & Greenberg, 2013; von Bastian et al., 2016; Kousaie & Phillips, 2012). For example, the studies done on large samples of bilingual and monolingual children have found out that there are no differences on Stroop task and the Attention network task (ANT) between the two groups (Duñabeitia et al., 2014; Antón et al., 2014). However, there is research evidence for the difference among bilinguals and monolinguals in cognitive control among young adults and elderly population (Kroll & Bialystok, 2013). In a study conducted using the English-word Stroop task by Brill & Green (2013) on Russian-English bilinguals and English monolinguals, it was found that while the monolinguals showed no interference during the Russian Stroop task and huge interference during the English Stroop task, bilinguals displayed as much interference for the Russian Stroop task as they accomplished for the English one. This recommends that bilinguals unknowingly access the two dialects at the same time. Language proficiency is a feasible measure of bilingualism (Kar

and colleagues, 2011) as it regulates the control over language among bilinguals (Costa et al., 2004) and it can be defined as the amount of control an individual has over a language (Hernandez & Li, 2007). According to the *language proficiency hypothesis (LPH)* given by Mägiste (1984), if the bilingual Stroop colour-naming task is in the dominant language, it should create more interference effect than in the less proficient language and that if the bilinguals are balanced then the interference created by the two languages should become equivalent. Interference in the Stroop task occurs when the automaticity of reading draws out the time taken to zero in on the colour and produce a reaction, while Stroop Facilitation highlights more limited reaction times (RTs) when the stimuli are introduced congruently, for instance the word 'BLUE' written in blue colour ink, and do not feature this conflict (Van Heuven et al., 2011). To rule over the difference in between the ink colour of the word and the word written, the conflict resolution processes and cognitive control is required, these skills are already utilised by bilinguals to choose between two languages (Van Heuven et al., 2011), as a result bilinguals perform better on Stroop task and other executive control tasks as compared to monolinguals (Bialystok et al., 2008). It has been suggested that the level of proficiency of two languages of bilinguals influences the amount of inhibition to the non-target language: the higher the difference in the level of proficiency, the lower will be the interference effect (Costa's et al., 2006). Studies conducted on language control and cognitive control (general purpose) have shown that language proficiency has an influence on interference control, inhibition and anticipation (Singh & Mishra 2012; Singh & Mishra 2013; Costa et al., 2004). Second language proficiency improves the anticipation, selection of words that is language specific and preparation of language specific words. Later studies allude to the distinction in the degree of bilingualism to the bilingual benefit: the higher the degree of bilingualism and the lower the period of acquisition of the L2, the higher the bilingual benefit (Incera & McLennan, 2017; Yow & Li, 2015). Therefore, overall evidence indicated that the

cognitive advantage that bilinguals have over monolinguals is not a very significant phenomenon as it can be subject to the influence of task specific mechanisms and other non-linguistic factors. This is the primary motivation towards further digging deep into understanding the relationship between bilingualism and cognitive control. Moreover, the studies that have been conducted on the bilingual cognitive advantage have primarily focused on the plain comparison between bilinguals and monolinguals, whereas the other factors like frequency of usage of a particular language on a daily basis, language proficiency, age of acquisition of second language and task-context based effects (i.e., switch from one language to another) should also be taken under consideration. The literature available on bilingualism and the colour-word Stroop task revealed a lack of studies that have used Hindi as the test language. Since India is a developing country, and everyone is not well-versed in English, the population that can be tested on the English language cognitive tests (for example, Stroop task) is limited. Apart from the deficiency of the sample, previous studies have shown mixed findings. For example, some studies have found that the response time on incongruent conditions, inhibition of non-target language, and Stroop effect was significantly more in the non-dominant/less proficient/second language as compared to the highly proficient language (Datta, 2019; Gerhand et al., 1995; Rosselli et al., 2002; Fang et al., 1981; Ehri & Ryan, 1980). Whereas the traditional language proficiency hypothesis states that the proficiency of the language is directly related to the interference in the Stroop task (Magiste, 1984). In the first study, the Stroop task has been made more complex by adding in both language and condition factor in the same task, making the task more demanding in terms of cognitive control, unlike most of the previous studies conducted using Stroop paradigm. Whereas in the second study, a separate block of the experiment is allotted to the Hindi language and English language with a time gap in administration of both the blocks to the same participant. The aim of the current study is: (a) To examine within-subject interference in language among low and high proficient

bilinguals that consisted subjects who were Hindi natives and had English as their second language using mixed Stroop task which consisted of manipulation of two languages particularly Hindi and English; (b) To investigate whether both languages have similar Stroop Effect. Based on the previous review of literature it was predicted that if Stroop interference is modulated by language and condition, we would expect to see higher interference independent of the language in mixed design of the Stroop task. It was also predicted that if Stroop interference is modulated by language, then the higher the level of interference expected in the first language (L1) as compared to second language (L2) in the separate block design of Stroop task.

#### **1.4 Summary**

In summary, the bilingual executive control explanation, which predicts overall reaction times for all types of trials, can explain a variety of data. However, the majority of such findings have come from studies that contrasted bilinguals and monolinguals. We intended to examine whether bilingual language fluency could affect the overall response time advantage when comparing L1 and L2 in mixed and separate block conditions. The evidence from the previous literature suggests that the cognitive advantage that bilinguals have over monolinguals is not a very significant phenomena, as it can be influenced by task-specific mechanisms and other non-linguistic factors such as interest in the task, length of the task, monotony of the task etc. After a considerable number of studies done with the colour word Stroop task there is still a constant debate as to which out of L1 and L2 shows a greater Stroop effect when the task is less demanding (L1\*Condition or L2\*Condition) as compared to when the task is cognitively more demanding (L1L2\*Condition). Therefore, we presented a bilingual version of the Stroop to Hindi-English bilinguals and altered their expectations about written language in the first study, whereas, in the second study we presented participants with a separate block for both Hindi and English language (i.e., expected task). Stroop interference is insensitive to the

proportion of words in a particular language if the subject has no control or cannot prevent the reading of the irrelevant colour word even when it is expected. If the subject can regulate his or her reading, Stroop interference in the expected language should be less than that in the unexpected language. However, the relationship between expectations and Stroop interference may be more nuanced than this. The subjects should be better at handling the more often used language. When compared to the language unexpected condition, this should contribute to a reduction in Stroop interference in that language, whereas expectation may not alter Stroop interference in the less known language. The trial involved native Hindi speakers whose second language was English. Inhibiting irrelevant reading processes enables control over cognitive functioning. Consequently, one would anticipate a decrease in Stroop interference. Specifically, due to greater fluency and usage of English compared to their native language Hindi, a reduction in Stroop interference may be observed in English. However, it remains uncertain whether the same applies to Hindi, as it is the participants' less frequently used language for the colour naming in day-to-day life.

## CHAPTER-2

### STUDY 1 – MIXED DESIGN OF STROOP TASK

#### 2.1 Introduction

In this study, the Stroop task has been made more complex by adding in both language and condition factor in the same task, making the task more demanding in terms of cognitive control, unlike most of the previous studies conducted using Stroop paradigm. The task consists of randomly displayed trails of Hindi and English words as well as variations in congruency, i.e., congruent & incongruent Hindi trials; and congruent & incongruent English trials being displayed randomly. This makes it more difficult for the individual to ignore the meaning of the word (in case of incongruent trials) and focus on detecting the congruent and incongruent trials, because the language factor and condition factor both are taking place in the same experiment. Based on the previous review of literature it was predicted that if Stroop interference is modulated by language and condition, we would expect to see higher interference independent of the language in mixed design of the Stroop task. There are two models suggested by Potter et al. (1984) that allow us to conclude how bilinguals store and access lexical information in their memory: The Word Association Model (WA) and The Concept Mediation Model (CM). Based on these, researchers have suggested two hypotheses: (1) the word association model suggests that the individuals' first language (L1) and second language (L2) are directly linked; (2) the concept mediation model suggests that there is no link between the first and second language of an individual at the lexical level, but they have a common semantic representation (Kroll & Stewart, 1994). A study conducted by Ning (2021) suggests that the processing automaticity of the distractor and the binding between target and distractor are related to how language proficiency affects both the Stroop effect and the reverse-Stroop effect. According to the findings, the Stroop effect and reverse-Stroop effect were,

respectively, stronger in the dominant language context than they were in the non-dominant language context. The findings also imply that it is somewhat more difficult to draw attention to the non-dominant language. Hence, it is neither easy to cause interference nor easy to be interfered when the non-dominant language is considered.

The level of L2 proficiency (Mägiste, 1984; Zied et al., 2004), L2 - age of acquisition of L2 (Tzelgov, Henik, Leiser, 1990; Hernandez, Li, 2007), and similarity of L1 and L2 are the three main factors suggested to influence the pattern of between- and within-language interference in the bilingual Stroop task (Chen, Ho, 1986; Lee, Chan, 2000; Sumiya, Healy, 2004). The variables interact to affect the bilingual mental lexicon; their proportional contributions to each are still up for debate. The key component impacting multilingual processing is thought to be language competency, which is the degree of control one has over a language (Hernandez, Li, 2007). Costa et al. (2006) investigated the effects of language similarity, L2 age of acquisition, and L2 proficiency on the bilingual language-switching performance over the course of four experiments. He discovers that neither the similarity of the languages nor the age at which the second language was acquired much affects how bilinguals manage the language switching job.

This study was done to see the within – subject effects when patients performed the mixed Stroop task that involved a more complex mix of both English and Hindi language; and congruent and incongruent trials in the same task. Therefore when the task becomes more demanding, we are looking to investigate as to which language produces a significant Stroop effect. (Sir for this you asked to write citation but I did not understand it. This data is in relevance to our current study, so I am not able to figure out how to cite it)

## 2.2 Methodology

### **2.2.1 Participants**

The research study sample included a total of 24 student volunteers from Thapar Institute that were recruited for the study on the basis of the following criteria: a) age-range of 18-25 years; b) native Hindi (L1) speakers with English (L2) as their second language; c) at least 7 years of basic education in both languages. The mean age of the participants was 21.35 years. The mean language proficiency was 7.43 for Hindi and 8.27 for English on a scale of 0–10. Subjects were asked whether which language (out of L1 & L2) was used when talking about colours red, blue, green and yellow on a daily basis in formal and informal settings. All of the people that took part were right-handed. No participants reported any history of neurological condition or colour blindness.

### **2.2.2 Design**

The within subject design was used to see the differences in the response time within a group on various conditions (congruent and incongruent) of the Stroop task wherein the colour and language were varied from trial to trial. The independent variables in this study were conditions of the Stroop task and language, and the reaction time was used as the dependent measure.

### **2.2.3 Tools Used**

- 1) **Language background questionnaire** - was administered to each individual to collect information about language use at different ages and communication with family, friends, school, reading, frequency of use of Hindi (L1) and English (L2), exposure and self-rated proficiency across languages, language domains and contexts for both Hindi (L1) and English (L2) for reading, writing, speaking, listening, syntax & dependence on language.
- 2) **LexTale test** - was also performed. LexTale is a short lexical decision test that can be used to assess non-native speakers' English proficiency. LexTale is a test of English

vocabulary knowledge that is used to assess English proficiency of the participants (Lemhöfer & Broersma, 2012). The LexTale test has been previously used as a measure of second language proficiency in bilingualism research on Hindi-English bilingual adults in India (Khare et al., 2013). The participants are required to decide if the In this test a string of letters is presented one at a time, the participants are required to decide if the string of letters is a word or a non-word in English. The proficiency score (in %) based on the LexTale test was generated after the completion of the test. High-proficiency bilinguals obtained a significantly higher score (accuracy) than the low-proficiency bilinguals on the LexTale test and this performance also corresponded with the proficiency ratings on the language background questionnaire.

- 3) **Mixed Stroop Task** The Stroop Task, is one of the most well-known psychology experiments used in various cognitive psychology experiments. In the present study we used congruent and incongruent condition. There were a total of 300 trials in the experiment. The participant required to respond to the trials which consisted of coloured words as soon as possible by pressing the dedicated keys assigned for congruent and incongruent condition. For half of the participants the key for congruent condition was “L” and for incongruent condition it was “A”, whereas for the other half the key dedicated for the congruent condition was “A” and for the incongruent condition it was “L”. This was done to avoid any kind of bias related to the positioning of the dedicated keys on the keyboard. In a congruent task, the colour of the word and the meaning remains the same (e.g., BLUE written in blue colour ). However, in an incongruent trial, the colour of the word is not in sync with its meaning (e.g., GREEN written in red colour). The subject is supposed to detect the whether the trial is congruent or incongruent. The task consists of trails of words in both Hindi and English being displayed randomly along with the variation in the congruency. The participants

were also asked for the age of acquisition of second language as it has been found to interact with executive control mechanisms among bilinguals (Luk et al., 2011). The Stroop effect is calculated by subtracting the reaction time for the incongruent condition from the reaction time for the congruent condition. The task illustration is given in the figure below, wherein a black screen with a plus sign was shown for 500ms followed by a black screen with a stimuli (name of colour in Hindi, name of the colour in English) that was flashed for 300ms followed by another blank black interval in which the subject was supposed to respond. A schematic illustration of a trial of the Stroop task was given.

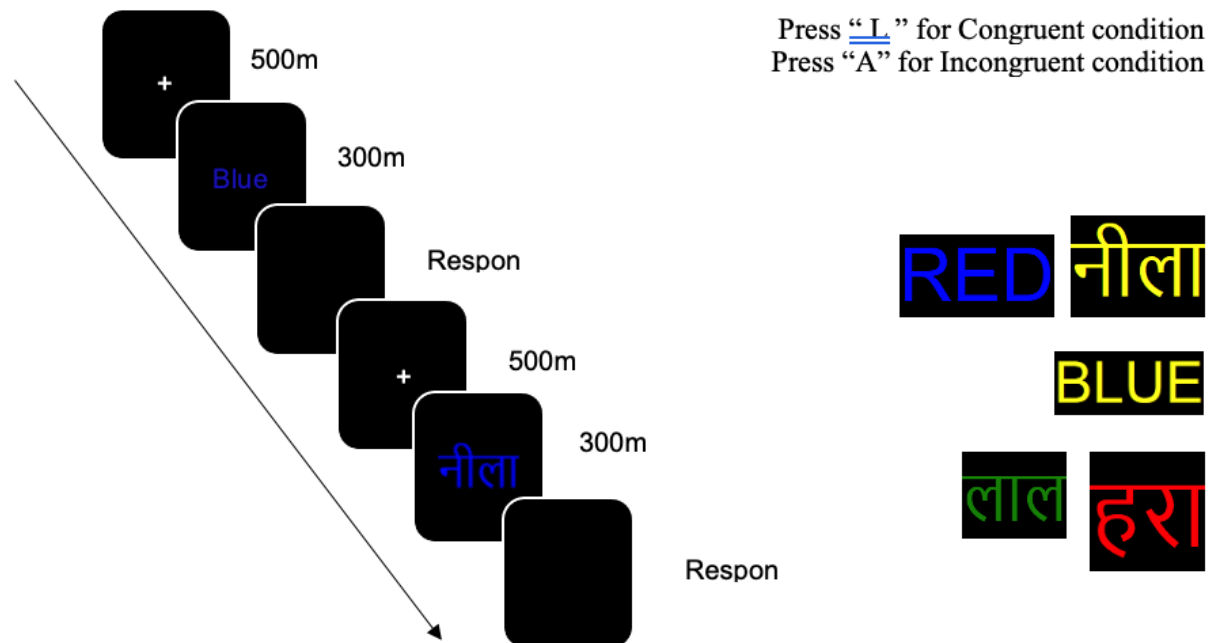


Figure 1

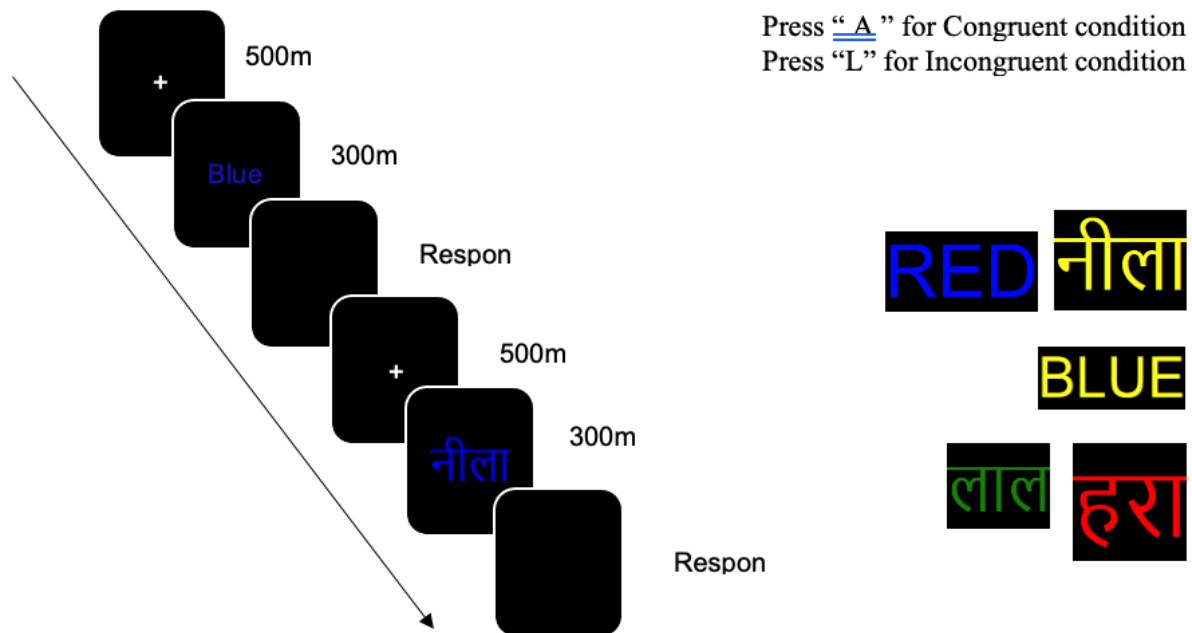


Figure 2

#### 2.2.4 Procedure

The participant was instructed to sit comfortably in a dark, noise-free room. An Informed Consent was taken from the participants wherein they were briefed about the experiment and were assured that they were free to withdraw from the experiment whenever they wished. The participants were tested in both native (Hindi) and English language versions of the computerized colour-word Stroop task. In both situations, subjects responded to congruency by pressing a specific key on the keyboard (e.g. "L" for congruent, "A" for incongruent). Post the experiment, respondents were asked to indicate which language they used out of their native and second language for producing these words on a daily basis.

#### 2.2.5 Measures of performance

The reaction time was calculated for each trial in all the conditions in both the languages (Hindi & English). Based on this reaction time, the facilitation, inhibition, and Stroop effect were calculated for all the subjects in both languages, i.e., Hindi & English. To calculate facilitation for each trial, the reaction time for the congruent condition was subtracted from the reaction time from the neutral condition. A facilitation effect happens when the participant needs to

manage a congruent trial: the time expected to name the colour of the congruent trials is lower than the time expected to name the colour of the control trials. Inhibition for each trial was calculated by subtracting reaction time of incongruent condition from reaction time on neutral condition. An interference effect happens on the grounds that the automatic reading process and the colour naming process are in struggle. The time expected to name the colour of the incongruent trials, be that as it may, is longer than the time expected to name the colour of the control trials. This effect is known as the interference effect. Finally, to estimate the Stroop interference/effect i.e., the sum of interference effect and facilitation effect, the reaction time for incongruent condition was subtracted from the reaction time for congruent condition. On the basis of the above calculations, a comparison was made between the facilitation, inhibition & Stroop effect.

### 2.3 Results

For the purpose of the present study, bilinguals were recruited to evaluate their performance on Hindi-English Stroop task. The mean age of the participants was 21.35 years. The mean language proficiency was 7.43 for Hindi and 8.27 for English on a scale of 0–10.

**Table-2.1: Descriptive Statistics**

Language	Condition	N	Mean	SD	SE	Coefficient of Variation
English	Congruent	24	422.049	115.826	23.643	0.274
	Incongruent	24	588.487	166.667	34.021	0.283
Hindi	Congruent	24	523.382	178.358	36.407	0.341
	Incongruent	24	583.164	174.768	35.674	0.300

Table 1 shows the descriptive statistics for 24 participants who performed the Hindi-English Stroop task.

The mean RT for congruent-English condition was 422.049 (SD = 115.826), whereas for congruent-Hindi condition it was 523.382 (SD = 178.358). The mean for incongruent-English condition was 523.382 (SD = 166.667), whereas for incongruent-Hindi condition it was 583.164 (174.768). The standard error for congruent-English condition was 23.634, for incongruent-English condition it was 34.021, for congruent-Hindi condition it was 36.407, and for incongruent-Hindi condition it was 35.674. The coefficient of variation for congruent-English condition was 0.274, for incongruent-English condition it was 0.283, for congruent-Hindi condition it was 0.341, and for incongruent-Hindi condition it was 0.300.

**Table-2.2: Repeated Measures ANOVA**

Cases	Sum of Squares	df	Mean Square	F	p	$\eta^2$
Language	55308.340	1	55308.340	4.177	0.053	0.154
Residuals	304579.006	23	13242.565			
Condition	307051.408	1	307051.408	26.57 3	< .001	0.536
Residuals	265767.457	23	11555.107			
Language * Condition	68252.538	1	68252.538	4.764	0.040	0.172
Residuals	329546.066	23	14328.090			

*Note.* Type III Sum of Squares

There was a significant main effect of language on condition ( $F(1,23) = 4.177, p = 0.053$ , partial  $\eta^2 = 0.154$ ). There was a significant interaction effect of condition into language ( $F(1,23) = 26.573, p < .001$ , partial  $\eta^2 = 0.536$ ). There was no significant main effect of language.

**Table-2.3: Simple Main Effects**

Level of Language	Sum of Squares	df	Mean Square	F	p
English	332417.432	1	332417.432	27.686	< .001
Hindi	42886.515	1	42886.515	3.091	0.092

There was a significant Stroop effect in English language ( $F(1,1) = 27.686, p = <.001$ ), but not in Hindi language.

**Graph-2.1: Bar Plot for English language**

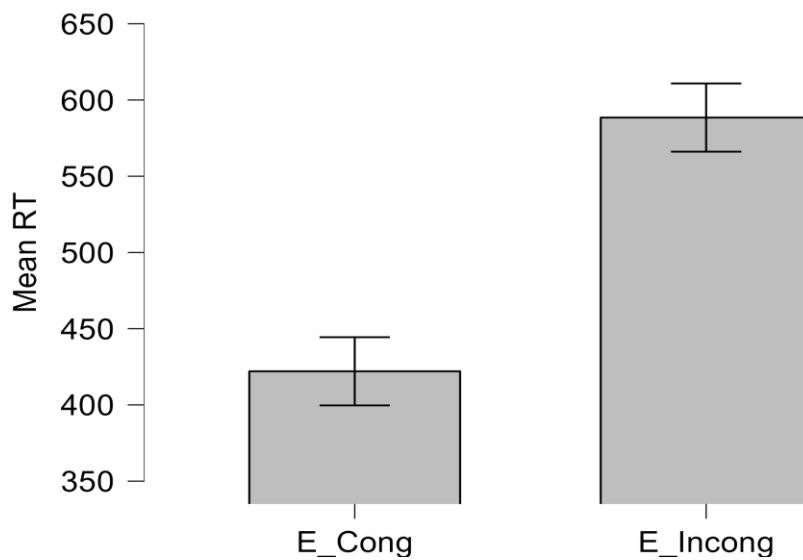


Figure 3

**Graph-2.2: Bar Plot for Hindi language**

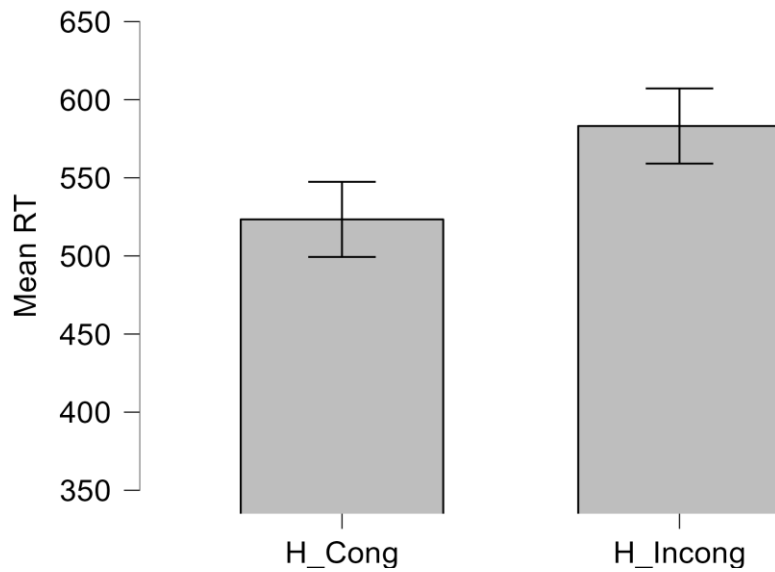


Figure 4

## 2.4 Discussion

This study aimed to examine within-language interference using the Stroop task among native language (Hindi) and second language (English) bilinguals, and to analyse the impact of language proficiency on a complex mixed language-condition Stroop task. All the participants reported more proficiency in the English language (8.27) as compared to the Hindi language (7.43). Based on the previous review of literature it was predicted that if interference is modulated by language and condition, there will be Stroop effect independent of the language. Results of the within-group comparison indicated significant differences in participant's performance on the mixed Hindi-English version of the Stroop task. English being the second language and more proficient language, participants showed significantly more Stroop interference in the English-incongruent condition as compared to Hindi-incongruent condition. Whereas, the interference was less in English-congruent condition as compared to Hindi-congruent condition. There was a significant Stroop effect in English language but not in the Hindi language.

The ongoing study is in tandem with a study led by Suarez et. al., (2014) showed that familiarity with a subsequent language offers a genuine benefit in the capacity to restrain the undesirable proponent response in the first language, and that this effect is unaffected by variations in educational levels. The most important conclusion was, that while assessing individuals in their native language, second language capability ought not be ignored, as it seems to work on inhibitory control. Research has indicated that low proficiency second language users do not inhibit their first language, but use it to access the second language, however this is not the same for high proficiency second language users (Tzvelgov et al., 1990). Past studies have recommended that second language immersion decreases both the recurrence of use and the availability of the primary language (Linck et al., 2009). It was discovered that the Stroop effect was larger in highly proficient second language (English) as compared to Chinese, which was their native language (Fang et al., 1981). Gerhand et al., (1995) found that participants showed statistically more word meaning interference in English than in Gaelic (mother tongue).

This experiment was carried out on well-educated college students who were fluent in English; as a result, even native Hindi speakers were more fluent in English (second language). Furthermore, three primary colours (Red, Yellow, and Blue) were used in this experiment, which were very basic words and are commonly used in daily conversations. The subjects were asked whether they used their native language i.e. Hindi or their second language i.e. English when using these words in their day to day conversations. It was seen that all individuals indicated that they used their second language more often as compared to their native language on a daily basis.

## **2.5 Summary**

The aim of the study was to analyse within-language interference between Hindi and English bilinguals and to see the effect of language proficiency on performance on the mixed Stroop

task. It was found that in comparison to the Hindi trials in the Stroop Task, the response time on incongruent conditions, inhibition, and the Stroop Effect was much longer in English trials. Whereas, it was seen that the interference, inhibition, and the Stroop Effect was less in English-congruent condition as compared to Hindi-congruent condition. There was a significant Stroop effect in English language but not in the Hindi language. It was determined that because participants were more fluent in English language than in Hindi language, they displayed higher interference in English language as compared to Hindi language in the incongruent condition however, the results reversed in the congruent condition. Overall, the response time was higher for the incongruent trials as compared to the congruent trials in both English and Hindi language. Because of the lack of Hindi Stroop task in India, these discoveries might have significant clinical implications.

## **CHAPTER-3**

### **STUDY 2 – SEPARATE BLOCK DESIGN OF STROOP TASK**

#### **3.1 Introduction**

The basic paradigm of the colour-word Stroop task can be modified according to requirements of the research demands to delve deep into understanding the various factors that play a role in variances in Stroop performance. In the separate block design of the Stroop task there is a separate block made for the Hindi version of the task and a separate block for the English version of the Stroop task. Each block consists of 150 trials each. Within these 150 trials are present the congruent and incongruent trials for each language and the subject is required to respond with a particular key on the keyboard indicating the trial is congruent or incongruent. There is a break given in administration of both the blocks to avoid any carryover effects. This experiment is designed separately for each language to examine the effect of language (i.e., first language (L1) or second language (L2)) on the interference in the Stroop task. Based on the previous literature it was predicted that if Stroop interference is modulated by language, then the higher the level of interference expected in the first language (L1) as compared to second language (L2) in the separate block design of Stroop task.

Participants in the analysis of a study conducted by Hu, Kang & Mao (2022) took longer to complete the Stroop task properly in the second language version than in the native language version, indicating that the main effect of language type was significant. Additionally, neither the main effect of word colour consistency nor their interaction was determined to have significance. This study showed that the results of the Stroop test were significantly influenced by language type. However, according to some studies, language variations have no effect on

Stroop. The findings of Biederman & Tsao (1979), which claimed that there were no appreciable differences between Mandarin and English in the Stroop test, were questioned by Smith and Kirsner (1982). Additionally, they discovered that individuals who are Chinese-English bilinguals and whose mother tongue is Chinese exhibit less Stroop effect in Chinese than in English. Another earlier study discovered that the Stroop effect was not significantly different depending on whether the test was written in Mandarin or English (Lee & Chan, 2000).

Considering the discrepancy between the various studies. The current study compares the Stroop effect between Hindi and English for bilinguals who speak both languages. Here, the task is made more simpler, as it has a separate block for each language. All of the participants speak Hindi as a first language; thus, they are all more fluent in it. Furthermore, there may be greater interference between a word's meaning and colour. The study's hypothesis is that bilinguals in Hindi and English who performed the Hindi version of the Stroop test will exhibit a stronger Stroop test effect than those who performed the English version.

## **3.2 Methodology**

### **3.2.1 Participants**

The research study sample included 25 young adults who performed the Hindi version of the Stroop task and 22 young adults who performed the English version of the Stroop task, ranging from 18 to 25 years old. The native languages of all participants was Hindi (L1) and their second language was English (L2). Subjects were asked to rate on a scale of 1-10 as to how often they used Hindi language on a daily basis and the average response out of 10 was 6.1; similarly, the subjects were asked how often they used English language on a daily basis and the average response out of 10 was 7.5; at last they were asked which language out of Hindi and English did they use when they referred to the names of colours flashed on their screen during the experiment and only 3 out of 25 responded with Hindi while the rest of them responded

with English. All of the people that took part were right-handed. No participants reported any history of neurological condition or colour blindness.

### **3.2.2 Design**

This research study consisted of both between-group and within-group design using a separate block experiment. A between-group design was followed to see the differences between the Stroop effect of Hindi (group 1) and English (group 2) bilinguals. A within subject design was used to see the differences in the reaction time within a group on conditions (i.e., congruent & incongruent) of the Stroop task. The independent variables in this study were conditions and language of the Stroop task, and the response time was used as dependent measure.

### **3.2.3 Task**

The Stroop Task, is one of the most well-known psychology experiments used in various cognitive psychology experiments. In the present study we used congruent and incongruent trials. The experiment consisted of 150 trials for each block i.e., 150 for Hindi and 150 for English. The participant required to respond to the colour of the word as soon as possible by pressing the dedicated keys assigned for each colour. In a congruent task, the colour of the word and the meaning remains the same (e.g., GREEN written in green colour). However, in an incongruent trial, the colour of the word is not congruent with its meaning (e.g., GREEN written in yellow colour). The subject is supposed to press 'A' for the congruent condition and 'L' for the incongruent condition. The Stroop effect is calculated by subtracting the reaction time for the incongruent condition from the reaction time for the congruent condition.

The task illustration is given in the figure below, wherein a black screen with a plus sign or was shown for 500ms followed by a black screen with a stimuli (name of color in English) that was flashed for 300ms followed by another blank black interval in which the subject was

supposed to respond. The same sequence was followed for the other language i.e., Hindi. A schematic illustration of a trial of the Stroop task was given.

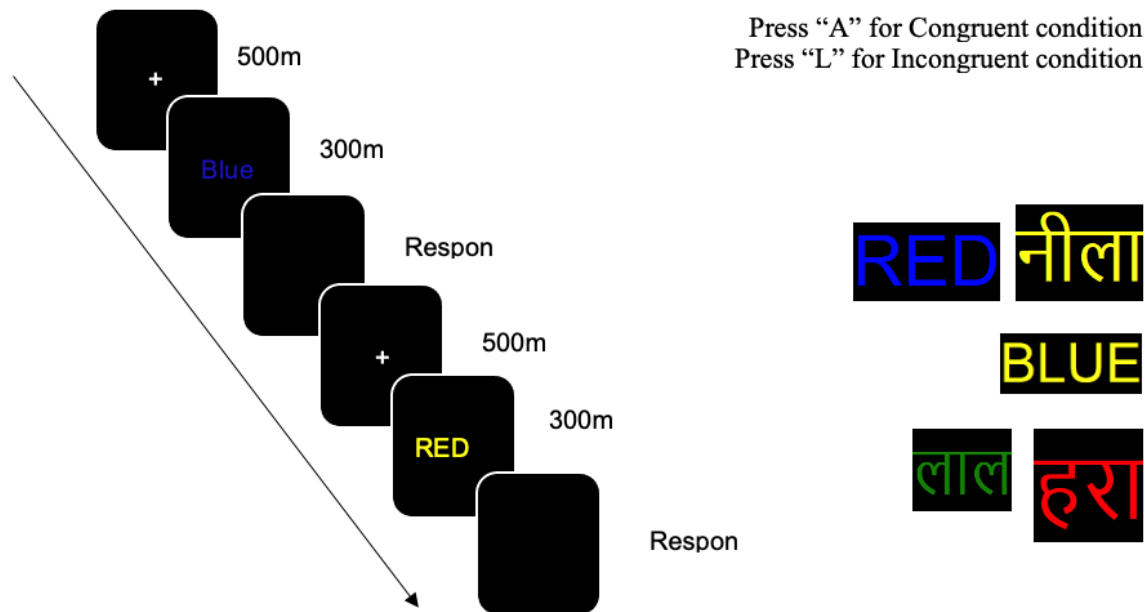


Figure 5

### 3.2.4 Procedure

The participant was instructed to sit comfortably in a dim-lit, noise-free room. An Informed Consent was taken from the participants wherein they were briefed about the experiment and were assured that they were free to withdraw from the experiment whenever they wished. The participants were tested in both native (Hindi) and English language version of the computerized colour-word Stroop task designed using Open sesame software. In all three situations, subjects responded to congruent or incongruent condition by pressing a specific key on the keyboard ('A' for congruent, 'L' for incongruent). A total of 10 minutes gap was given between the two versions (Hindi and English) of the Stroop task. During this time of relaxation, respondents were asked to complete a questionnaire in which subjects were asked to rate on a scale of 1-10 as to how often they used Hindi language on a daily basis, how often they used English language on a daily basis, and which language out of Hindi and English did they use

when they referred to the names of colours flashed on their screen during the experiment.

### **3.2.5 Measures of performance**

The reaction time was calculated for each trial in all the conditions in both the languages (Hindi & English). Based on this reaction time, the facilitation, inhibition, and Stroop effect were calculated for all the subjects in both languages, i.e., Hindi & English. To calculate facilitation for each trial, the reaction time for the congruent condition was subtracted from the reaction time from the neutral condition. A facilitation effect happens when the participant needs to manage a congruent trial: the time expected to name the colour of the congruent trials is lower than the time expected to name the colour of the control trials. Inhibition for each trial was calculated by subtracting reaction time of incongruent condition from reaction time on neutral condition. An interference effect happens on the grounds that the automatic reading process and the colour naming process are in struggle. The time expected to name the colour of the incongruent trials, be that as it may, is longer than the time expected to name the colour of the control trials. This effect is known as the interference effect. Finally, to estimate the Stroop interference/effect i.e., the sum of interference effect and facilitation effect, the reaction time for incongruent condition was subtracted from the reaction time for congruent condition. On the basis of the above calculations, a comparison was made between the facilitation, inhibition & Stroop effect.

### **3.3 Results**

For the purpose of the present study, bilinguals were recruited to evaluate their performance on Hindi and English versions of the Stroop task. It was predicted that if Stroop interference is modulated by language, then the higher the level of interference expected in the first language (L1) as compared to second language (L2).

#### **Table-3.1: Descriptive Statistics**

	Cong		Incong	
	English	Hindi	English	Hindi
<b>Valid</b>	22	25	22	25
<b>Missing</b>	0	0	0	0
<b>Mean</b>	461.775	568.476	466.088	576.739
<b>Std. Deviation</b>	121.906	200.452	122.789	199.797
<b>Std. Error</b>	25.990	40.090	26.179	39.959
<b>Coefficient of Variation</b>	0.264	0.353	0.263	0.346
<b>Minimum</b>	213.348	249.000	222.280	243.722
<b>Maximum</b>	757.570	939.396	756.781	901.563

Table 1 shows the descriptive statistics for 22 participants who performed the English Stroop task and 25 participants who performed the Hindi Stroop task.

The mean RT for congruent-English condition was 461.775 (SD = 121.906), whereas for congruent-Hindi condition it was 568.476 (SD = 200.452). The mean RT for incongruent-English condition was 466.088 (SD = 122.789), whereas for incongruent-Hindi condition it was 576.739 (SD = 199.797). The standard error for congruent-English condition was 25.990, for incongruent-English condition it was 26.179, for congruent-Hindi condition it was 40.090, and for incongruent-Hindi condition it was 39.959. The coefficient of variation for congruent-English condition was 0.264, for incongruent-English condition it was 0.263, for congruent-Hindi condition it was 0.353, and for incongruent-Hindi condition it was 0.346.

**Graph-3.1: Descriptive Plots**

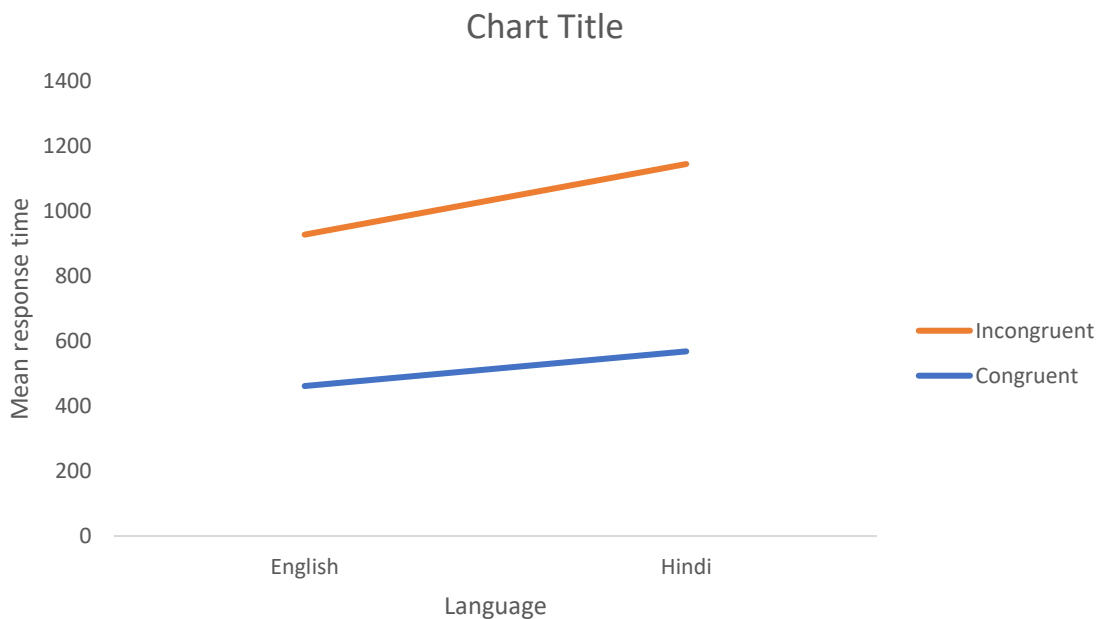


Figure 6

Graph-3.1 Shows the difference between mean RT of congruent and mean RT incongruent conditions of both Hindi and English language. The mean RT for congruent-English condition was 461.775, whereas for congruent-Hindi condition it was 568.476 seconds (SD = 200.452 seconds). Therefore, the graph clearly indicates a higher RT for Hindi language in congruent condition. The mean RT for incongruent-English condition was 466.088 seconds (SD = 122.789 seconds), whereas for incongruent-Hindi condition it was 576.739 seconds (SD = 199.797 seconds). Therefore, the graph clearly indicates a higher RT for Hindi language in incongruent condition as well.

**Repeated Measures ANOVA**

**Table-3.2: Within Subject Effects**

Cases	Sum of Squares	df	Mean Square	F	p
Condition	925.346	1	925.346	4.602	0.037
Condition * Group	91.258	1	91.258	0.454	0.504

Residuals	9049.352	45	201.096
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There was a significant main effect of condition ( $F(1,45) = 4.602, p = 0.037$ ). There was no significant interaction effect of condition into group.

**Table-3.3 Between Subjects Effects**

Cases	Sum of Squares	df	Mean Square	F	p
Group	276413.224	1	276413.224	4.893	0.032
Residuals	2.542×10+6	45	56490.019		

There was a significant effect of group ( $F(1,45) = 4.893, p = 0.032$ ).

**Table-3.4 Simple Main Effects**

Level of Group	Sum of Squares	df	Mean Square	F	p
English	204.644	1	204.644	4.976	0.037
Hindi	853.367	1	853.367	2.502	0.127

There was a significant Stroop effect in English language ( $F(1,1) = 4.976, p = <.037$ ), but not in Hindi language.

### 3.8 Discussion

This study aimed to examine between-language interference using the Stroop task among Hindi-English bilinguals whose native language was Hindi. of Based on the previous literature it was predicted that if Stroop interference is modulated by language, then the higher the level of interference expected in the first language (L1) as compared to second language (L2) in the separate block design of Stroop task. The results of between-group comparison indicated significant differences in participant's performance on Hindi and English versions of the Stroop task. Since English is the second language and more frequently spoken by individuals on a

daily basis, participants showed significantly Stroop effect in the English language but not in Hindi language. In the between subject effects, there was a significant effect of group. The individuals took longer to respond in the Hindi language as compared to the English language in both congruent and incongruent conditions. Therefore, irrespective of the condition, the participants took longer to respond to the Hindi trials. However, when considering the within-group statistics, there was a significant main effect of condition i.e., participants took longer to respond to the incongruent trials as compared to the congruent trials, however, no interaction effect was found between condition and group. Chen and Ho (1986) explored Stroop interference development in Chinese-English bilinguals. They discovered that the interference caused by the first language (Chinese) is greater than the interference created by the second language in the early stages of learning the second language (English). This holds true for both different language and same language situations. However, as one gains proficiency in the second language, the same language interference effect becomes stronger than the different language interference effect in that language. According to previous studies, the greater the automatic processing of the meaning of the word, the greater will be the interference in that word, and the more proficient will be the participants in stimulating that language. However, in a study conducted by Hu, Kang & Mao (2022), it was found that English was the individual's non-dominant language as compared to Chinese and the interference of word meaning was significantly higher in the English version of the Stroop task as compared to the Chinese version. The Stroop incongruent trial, according to Bialystok and colleagues (2008), is similar to the process that a bilingual individual goes through when trying to communicate in a second language while repressing their first. It's unclear if bilinguals are better at stopping non-target behaviour from the start, making learning a second language easier, or if the capacity to inhibit unwanted conduct improves as the person gets more bilingual and trains inhibitory control.

The participants used English more often than they used Hindi to communicate the four colours (i.e., Red, Green, Blue, Yellow) on a daily basis. The participants were asked which language out of Hindi and English did they use when they referred to the names of colours flashed on their screen during the experiment and only 3 out of 25 responded with Hindi while the rest of them responded with English. Therefore, this makes it clear that irrespective of Hindi being their mother tongue their performance was delayed in Hindi language because they were more often using the English language as a mode of communication.

### **3.9 Summary**

The aim of the study was to analyse between-language interference between Hindi and English bilinguals. It was found that in comparison to the English version of the Stroop Task, the response time on incongruent conditions, inhibition, and the Stroop Effect was much longer in Hindi version of the Stroop task. There was a significant Stroop effect in English language but not in the Hindi language. Irrespective of the condition, the participants took longer to respond to the Hindi trials. Overall, the response time was higher for the incongruent trials as compared to the congruent trials in both English and Hindi language. As a result, regardless of whether Hindi was their native tongue, their performance in Hindi was delayed because they used English as a medium of communication more frequently.

## **CHAPTER – 4**

### **GENERAL DISCUSSION**

It is worth noting that the overall RT advantage appears to appear when the activities are cognitively taxing. One method to make the process more difficult is to change the amount of monitoring required. Monitoring is seen as a crucial component of the executive control system (Posner, 1994). In the current study, we have examined Hindi-English bilinguals in high and low monitoring conditions. In the experiment 1, we had the high monitoring condition because participants were presented with L1, L2, congruent and incongruent trials in the same task. Whereas, in the second experiment which had low monitoring condition we had a separate task for both the languages (i.e., Hindi & English) which consisted of L1 or L2 along with congruent and incongruent trials. In both the tasks the participants had to detect whether the trial was congruent or incongruent by pressing on the designated keys. The results showed an overall advantage of bilinguals to perform faster on congruent trials as compared to incongruent trials. It was also observed that the participants took less time to respond to English trials as compared to Hindi trials irrespective of Hindi being their mother tongue and English being their second language. The participants also showed a significant Stroop effect in English language but not in Hindi language in both experiment 1 and experiment 2. The finding that extremely fluent bilinguals have frequent experience dealing with cross-linguistic impacts from two lexicons provides the justification for associating higher proficiency to enhanced executive control. Bilinguals must handle cross-linguistic impacts since they activate two lexicons in tandem in a language-independent manner. However, because this level of activation fluctuates with proficiency, the desire for the executive control system to intervene should be modulated.

Blumenfeld and Marian (2007) investigated the effect of language proficiency on parallel lexicon activation using the visual world eye tracking paradigm with German-English and English-German bilinguals. Only very fluent German-English bilinguals activated German while processing English-specific targets, according to the findings. Others have found that better language proficiency results in stronger parallel activation of lexicons among bilinguals (Jared and Kroll, 2001; Van Hell and Dijkstra, 2002). Costa et al. (2009) stated that bilingual overall response time advantage is only observed when the monitoring situation is unpredictable and difficult. Furthermore, it has been proposed that bilinguals may benefit from congruent trials only in mixed blocks of trials, as this requires ongoing monitoring and goal-maintenance (Bialystok et al., 2006; Costa et al., 2008; Bialystok, 2010). Bialystok and Martin (2004) discovered a global response time advantage in a task with no explicit conflict but participants operating under higher cognitive load.

Other data suggests that bilingualism may affect the attention system in general, rather than only the inhibitory control system. Emmorey et al. (2008) used a modified Flanker's task with go/no-go blocks and conflict trials to compare bimodal and unimodal bilinguals with monolinguals. The response inhibition conditions had no group differences, however unimodal bilinguals were faster on both incongruent and congruent trials. The scientists concluded that multilingual executive control advantage increases the interference suppression system, allowing them to better handle the conflict, whereas no indication of a superior response inhibition mechanism was found. These findings show that bilingual advantage is more prevalent when complicated decision-making is involved, as achieved through efficient interference control. Because these findings do not indicate to an exclusive inhibitory control mechanism and reveal general response time advantage with or without specific conflict or facilitation advantage, Hilchey and Klein (2011)'s general executive control advantage theory can accommodate these facts.

An inhibitory control account is complicated by bilinguals' higher performance on congruent and neutral trials in a conflict task. In an influential meta-analysis of various bilingual cognitive advantage research, Hilchey and Klein (2011) found that while most studies found a global response time advantage for bilinguals, few identified statistically significant reduced conflict or facilitation effects. As a result, Hilchey and Klein (2011) hypothesised that bilinguals may not have any inhibitory control but may have superior attentional mechanisms and goal-maintenance abilities. According to Hilchey and Klein's Bilingual Executive Process Advantage, bilinguals will display domain general executive control advantage on all types of trials, including conflict trials. This advantage is often manifested in faster RTs on tasks that involve some type of interference control and may or may not be conflicting. Most importantly, the executive control advantage theory highlights bilinguals' superior goal-directed attention regulation. This does not always refer to the ability to exercise reactive kinds of inhibitory control on conflicting tasks. Top-down attention control is also possible with a superior executive control system on tasks that need goal maintenance, monitoring, and interference suppression. Bilinguals' superior performance on congruent trials may be due to their ability to recognise facilitative cues in the context (Bialystok, 2010). Tao et al. (2011) investigated the impact of L2 acquisition age on executive control in early and late bilinguals. Their results on the lateralized attention network experiment revealed that low proficient bilinguals performed better at monitoring processes, whereas late and balanced bilinguals performed better at conflict resolution. To summarise, it appears that both age of acquisition and current proficiency have an effect on bilinguals' executive control systems. It is not always true that bilinguals who learned their second language later are unbalanced, and vice versa. Bilinguals who are more balanced may require a different type of inhibitory control mechanism than bilinguals who are less balanced, because they may activate superfluous lexicons to varying degrees. As a result, it is critical to explain bilingual cognitive advantage data on non-linguistic

stimuli from these perspectives. Calabria et al. (2012) examined highly accomplished bilinguals on linguistic and non-linguistic switch tasks. For the linguistic task, these bilinguals had symmetrical switch costs, but not for the non-linguistic task. Based on these findings, Calabria et al. (2012) hypothesised that bilinguals' language control system could be distinct from their overall executive control system, or possibly an independent entity. Bialystok et al. (2006) explored the presence of bilingual advantage on executive function components linked to monitoring and switching in highly skilled bilinguals, imbalanced bilinguals, and a monolingual control group. Participants were required to classify things visually while also processing auditory information. Interestingly, the imbalanced bilinguals scored in the middle of the bilinguals and monolinguals groups, but no dependable and meaningful difference was found. According to the study, fluent bilinguals are better at monitoring. Singh and Mishra (2012) compared two groups of Hindi-English bilinguals whose L2 competency on an oculomotor variant of the Stroop task differed (Hodgson et al., 2009). Participants were instructed to make an eye movement towards a colour patch that was similar to the colour in which the centrally displayed colour word was printed while avoiding distraction from the word's meaning. The findings revealed that bilinguals with superior L2 proficiency outperformed less proficient bilinguals in terms of overall speed and conflict resolution.

The Stroop effect's origin has been explained by a number of theories (MacLeod, 1991; Macleod & MacDonal, 2000). For instance, according to the principle of relative processing speed (Stroop, 1935), word processing is quicker than colour processing. Conflicting information will cause a delay in decision-making if the task is to report the colour because word information gets to the decision-making stage before colour information does. On the other hand, if the task is to report the word, a decision can be reached prior to the arrival of conflicting information. The automaticity theory, on the other hand (Marcel, 1983; Brown et al., 2002), highlights that while reading words is an automatic process that does not require

directed attention, recognising colours is not effortless and requires more attentional resources. The distinction between the two ideas is that the automaticity theory stresses that interference arises throughout the duration of processing, not just at the late stage, whereas the relative speed of processing hypothesis emphasises that interference arises at the decision-making or reaction stage. Additionally, automatic processes must be learned, and a fast but poorly learned process can obstruct a slower but better learned process (MacLeod, 1991). As a result, the automaticity theory, which is currently the most popular theory of the Stroop effect, also contributes to the explanation of the reverse-Stroop effect. Furthermore, the parallel-distributed processing theory (Cohen et al., 1992) emphasises that words and colours are processed in different pathways in parallel, and one of the pathways will eventually accrue enough output to exceed threshold and produce a response. This theory is designed to combine the benefits of the two theories mentioned above (MacLeod, 1991). In other words, what matters is the strength of the information flow down a particular pathway, not how quickly it moves. Additionally, automaticity depends on strength. Together, automaticity and attention are essential to illuminating the origin of the Stroop effect.

There are various ways in which we can use the Stroop task in the clinical field. The Stroop test reveals greater interference in a variety of mental illnesses, including dementia, schizophrenia, ADHD, and depression (Lansbergen et al., 2007; Spreen & Strauss, 1991). An emotional Stroop task (using depressing terms like "sadness," "aggression," and "suffering" in combination with more neutral words like "watch," "gate," and "footwear") has been designed for those with depression. According to research, those who experience depression are more inclined to pronounce negative words more slowly than neutral ones (Frings et al., 2010). These days, there are various Stroop test variants depending on the number of stimuli, the length of the task, the number of tasks and subtasks in the test, and the scoring method. The Stroop task paradigm's adaptability makes it valuable in many different areas of psychology. It has now

been expanded from a test that simply looked at the connection between word and colour processing to look into other processing interferences and make contributions to the disciplines of psychopathology and brain damage. The current task could also be helpful in detecting brain damage in bilinguals and monolinguals. The Stroop task can assist in separating the people who experienced brain damage from those who did not. These results were supported by subsequent research, and traumatic brain injury patients frequently take the Stroop test to evaluate their selective attention. Anterior cingulate cortex and dorsolateral prefrontal cortex, two brain areas that are active during settling conflict, are two of the functions of which have been identified through the application of the Stroop phenomenon in recent years. The dorsolateral prefrontal cortex appears to be involved in the necessary executive functions in the context of the Stroop task, particularly in maintaining response set (to name the colour, not to read the word), whereas the anterior cingulate cortex plays a crucial role in choosing the appropriate response and assessing its accuracy (Banich et al., 2000; Milham et al., 2003). In marketing, the Stroop effect is frequently used. Presentations and advertising are thoughtfully prepared, taking into account the font style and the colour of the print. According to the Stroop effect, people are typically more cognitively drawn to certain words and colours, which is why manufacturers carefully select the colours of their items. The mixed Stroop task that we used in experiment 1 could be manipulated and used to measure language proficiency, wherein the congruent trials would be a correct word and the incongruent trial could be a misspelled or incorrect word; and the subject has to indicate whether the words are correct or incorrect. This will help measure their proficiency in that particular language. After 80 years, one thing is still evident: this straightforward and reliable paradigm, as well as the interference phenomenon it illustrates, continue to offer helpful insights into how cognitive processes function. In 1935, it would have been difficult to have predicted that such a crucial tool could be produced by simply contrasting a few colours with their names. The invention of the Stroop task not only offers

fresh perspectives on how our brain mechanisms function, but it also shows how psychology may build on earlier research techniques as we continue to learn more and more about ourselves.

## **CHAPTER 5**

### **CONCLUSION**

The objectives of study 1 were to examine the effects of language competency on performance on the mixed Stroop task as well as within-language interference amongst bilinguals speaking Hindi and English. It was discovered that the response time on incongruent situations, inhibition, and the Stroop Effect in the English trials of the Stroop Task was much longer than it was in the Hindi trials. As opposed to Hindi, it was observed that the interference, inhibition, and Stroop Effect were less in the English-congruent condition. The Hindi language did not experience the same degree of the Stroop effect as the English language did. In the incongruent condition, it was shown that participants demonstrated stronger interference in English than in Hindi because they were more fluent in the former language; however, in the congruent condition, the results were the opposite. Overall, in both Hindi and English, the incongruent trials took longer to respond to than the congruent ones. These findings may have important therapeutic implications due to the paucity of Hindi Stroop task in India.

However, the aim of Study 2 was to examine interlanguage interference between bilinguals in Hindi and English. It was discovered that the Hindi version of the Stroop Task had much longer response times to incongruent situations, inhibition, and the Stroop Effect than the English version did. The Hindi language did not experience the same degree of the Stroop effect as the English language did. The participants took longer to respond to the Hindi trials regardless of the circumstance. Overall, in both Hindi and English, the incongruent trials took longer to respond to than the congruent ones.

Since barely everybody in India is familiar with English, the population that can be surveyed utilizing the Stroop task is seriously obliged. Second, because of changes in language expertise, there might be massive contrasts in execution among people who truly do communicate in English. Utilizing the Stroop task for instance, it is recommended that tests, especially those testing members' mental capacities, be created in the members' local language for further developed accuracy and reproducibility of the outcomes. One more implication of this study is that in the computerized age, paper-pencil variants of mental tests are becoming out of date. Besides, the electronic variant of these tests gives experts more precise outcomes and saves time, exertion, and cash while investigating the outcomes. There are not very many cognitive tests in Hindi, especially electronic cognitive tests. Thus, as well as acquiring a superior information on executive control and Stroop task execution in bilingual Hindi-English, an endeavour was made to plan a modernized form of the Stroop task that could be utilized with Hindi speakers. One limitation of the study was that the experiment was conducted on well-educated college students who were more fluent in the English language because it has been enforced onto them since childhood. Therefore, even native Hindi and Punjabi speakers were more fluent in their second language i.e., English, which left us at a disadvantage of not being able to reach the population that was more proficient in their native language. There are various future studies that can be conducted in the light of this study. This exact trial could be used with a sample of different languages, independent variables, Stroop tests, or age. Studies could be conducted to study the Stroop effect in language and condition mixed Stroop task; high proficient bilinguals Vs low proficient bilinguals; and Bilinguals Vs Monolinguals. Future studies have a ton of potential and are a thrilling headway later on and improvement of language.

## CHAPTER 6

### REFERENCES

- Abutalebi, J., & Green, D. (2007). Bilingual language production: The neurocognition of language representation and control. *Journal of Neurolinguistics*, *20*(3), 242–275. <https://doi.org/10.1016/j.jneuroling.2006.10.003>
- Algom, D., Chajut, E., & Lev, S. (2004). A Rational Look at the Emotional Stroop Phenomenon: A Generic Slowdown, Not a Stroop Effect. *Journal of Experimental Psychology*, *133*(3), 323–338. <https://doi.org/10.1037/0096-3445.133.3.323>
- Antón, E., Duñabeitia, J. A., Estévez, A., Hernández, J. A., Castillo, A., Fuentes, L. J., Davidson, D. J., & Carreiras, M. (2014). Is there a bilingual advantage in the ANT task? Evidence from children. *Frontiers in Psychology*, *5*. <https://doi.org/10.3389/fpsyg.2014.00398>
- Banich, M. T., Milham, M. P., Atchley, R., Cohen, N. J., Webb, A. G., Wszalek, T., Kramer, A. F., Liang, Z., Wright, A. C., Shenker, J., & Magin, R. L. (2000). fMRI Studies of Stroop Tasks Reveal Unique Roles of Anterior and Posterior Brain Systems in Attentional Selection. *Journal of Cognitive Neuroscience*, *12*(6), 988–1000. <https://doi.org/10.1162/08989290051137521>
- Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M. J., & Van IJzendoorn, M. H. (2007). Threat-related attentional bias in anxious and nonanxious individuals: A meta-analytic study. *Psychological Bulletin*, *133*(1), 1–24. <https://doi.org/10.1037/0033-2909.133.1.1>

- Bialystok, E. (2010). Global–local and trail-making tasks by monolingual and bilingual children: Beyond inhibition. *Developmental Psychology*, 46(1), 93–105. <https://doi.org/10.1037/a0015466>
- Bialystok, E., & Martin, M. Y. (2004). Attention and inhibition in bilingual children: evidence from the dimensional change card sort task. *Developmental Science*, 7(3), 325–339. <https://doi.org/10.1111/j.1467-7687.2004.00351.x>
- Bialystok, E., Craik, F. I. M., & Ryan, J. D. (2006). Executive control in a modified antisaccade task: Effects of aging and bilingualism. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 32(6), 1341–1354. <https://doi.org/10.1037/0278-7393.32.6.1341>
- Bialystok, E., Craik, F. I. M., Klein, R., & Viswanathan, M. (2004). Bilingualism, Aging, and Cognitive Control: Evidence From the Simon Task. *Psychology and Aging*, 19(2), 290–303. <https://doi.org/10.1037/0882-7974.19.2.290>
- Bialystok, E., Craik, F. I., Grady, C., Chau, W., Ishii, R., Gunji, A., & Pantev, C. (2005). Effect of bilingualism on cognitive control in the Simon task: evidence from MEG. *NeuroImage*, 24(1), 40–49. <https://doi.org/10.1016/j.neuroimage.2004.09.044>
- Bialystok, E., Craik, F., & Luk, G. (2008). Cognitive control and lexical access in younger and older bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 34(4), 859–873. <https://doi.org/10.1037/0278-7393.34.4.859>
- Biederman, I., & Tsao, Y. (1979b). On processing Chinese ideographs and English words: Some implications from Stroop-test results. *Cognitive Psychology*, 11(2), 125–132. [https://doi.org/10.1016/0010-0285\(79\)90007-0](https://doi.org/10.1016/0010-0285(79)90007-0)
- Blumenfeld, H. K., & Marian, V. (2007). Constraints on parallel activation in bilingual spoken language processing: Examining proficiency and lexical status using eye-tracking.

*Language and Cognitive Processes*, 22(5), 633–660.

<https://doi.org/10.1080/01690960601000746>

Blumenfeld, H. K., & Marian, V. (2007). Constraints on parallel activation in bilingual spoken language processing: Examining proficiency and lexical status using eye-tracking.

*Language and Cognitive Processes*, 22(5), 633–660.

<https://doi.org/10.1080/01690960601000746>

Brauer, M. (1998). Stroop interference in bilinguals: The role of similarity between the two languages. In A.F. Healy & L.E. Baurne, Jr. (Eds.). *Foreign language learning* (pp. 317–337). Mahwah, NJ: Erlbaum.

Bril, A., & Green, R. (2013). Bilingual Stroop in English Speakers with Russian as a Second Language: Exploring the Model of the Bilingual Mind. *Five*, 2(1), 7–11.

<https://doi.org/10.5642/five.20130201.03>

Brown, T., Gore, C. J., & Carr, T. H. (2002). Visual attention and word recognition in Stroop color naming: Is word recognition “automatic?” *Journal of Experimental Psychology: General*, 131(2), 220–240.

<https://doi.org/10.1037/0096-3445.131.2.220>

Buckley, T., Blanchard, E. B., & Neill, W. T. (2000). Information processing and PTSD: A review of the empirical literature. *Clinical Psychology Review*, 20(8), 1041–1065.

[https://doi.org/10.1016/s0272-7358\(99\)00030-6](https://doi.org/10.1016/s0272-7358(99)00030-6)

Calabria, M., Hernández, M., Branzi, F. M., & Costa, A. (2012). Qualitative Differences between Bilingual Language Control and Executive Control: Evidence from Task-Switching. *Frontiers in Psychology*, 2. <https://doi.org/10.3389/fpsyg.2011.00399>

Chen, H., & Ho, C. S. (1986). Development of Stroop interference in Chinese-English bilinguals. *Journal of Experimental Psychology: Learning, Memory and Cognition*,

12(3), 397–401. <https://doi.org/10.1037/0278-7393.12.3.397>

- Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic processes: A parallel distributed processing account of the Stroop effect. *Psychological Review*, 97(3), 332–361. <https://doi.org/10.1037/0033-295x.97.3.332>
- Cohen, J. D., Servan-Schreiber, D., & McClelland, J. L. (1992). A Parallel Distributed Processing Approach to Automaticity. *American Journal of Psychology*, 105(2), 239. <https://doi.org/10.2307/1423029>
- Costa, A., & Santesteban, M. (2004). Lexical access in bilingual speech production: Evidence from language switching in highly proficient bilinguals and L2 learners. *Journal of Memory and Language*, 50(4), 491–511. <https://doi.org/10.1016/j.jml.2004.02.002>
- Costa, A., Hernández, M., & Sebastián-Gallés, N. (2008). Bilingualism aids conflict resolution: Evidence from the ANT task. *Cognition*, 106(1), 59–86. <https://doi.org/10.1016/j.cognition.2006.12.013>
- Costa, A., Hernández, M., Costa-Faidella, J., & Sebastián-Gallés, N. (2009). On the bilingual advantage in conflict processing: Now you see it, now you don't. *Cognition*, 113(2), 135–149. <https://doi.org/10.1016/j.cognition.2009.08.001>
- Costa, A., Santesteban, M., & Ivanova, I. (2006). How do highly proficient bilinguals control their lexicalization process? Inhibitory and language-specific selection mechanisms are both functional. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 32(5), 1057–1074. <https://doi.org/10.1037/0278-7393.32.5.1057>
- Dash, T., & Kar, B. R. (2014). Bilingual Language Control and General Purpose Cognitive Control among Individuals with Bilingual Aphasia: Evidence Based on Negative Priming and Flanker Tasks. *Behavioural Neurology*, 2014, 1–20. <https://doi.org/10.1155/2014/679706>

- Datta, K., Nebhinani, N., & Dixit, A. (2019). Performance Differences in Hindi and English Speaking Bilinguals on Stroop Task. *Journal of Psycholinguistic Research*, 48(6), 1441–1448. <https://doi.org/10.1007/s10936-019-09667-6>
- Donnelly, S., Brooks, P. J., & Homer, B. D. (2019). Is there a bilingual advantage on interference-control tasks? A multiverse meta-analysis of global reaction time and interference cost. *Psychonomic Bulletin & Review*, 26(4), 1122–1147. <https://doi-org.ezproxy.tlu.edu/10.3758/s13423-019-01567-z>
- Dormal, V., & Pesenti, M. (2007). Numerosity-Length Interference. *Experimental Psychology*, 54(4), 289–297. <https://doi.org/10.1027/1618-3169.54.4.289>
- Duñabeitia, J. A., Hernández, J. A., Antón, E., Macizo, P., Estévez, A., Fuentes, L. J., & Carreiras, M. (2014). The Inhibitory Advantage in Bilingual Children Revisited. *Experimental Psychology*, 61(3), 234–251. <https://doi.org/10.1027/1618-3169/a000243>
- Dyer, F. N. (1971). Color-naming interference in monolinguals and bilinguals. *Journal of Verbal Learning and Verbal Behavior*, 10(3), 297–302. [https://doi.org/10.1016/s0022-5371\(71\)80057-9](https://doi.org/10.1016/s0022-5371(71)80057-9)
- Ehri, L. C., & Ryan, E. B. (1980). Performance of bilinguals in a picture-word interference task. *Journal of Psycholinguistic Research*, 9(3), 285–302. <https://doi.org/10.1007/bf01067243>
- Emmorey, K., Luk, G., Pyers, J., & Bialystok, E. (2008). The Source of Enhanced Cognitive Control in Bilinguals. *Psychological Science*, 19(12), 1201–1206. <https://doi.org/10.1111/j.1467-9280.2008.02224.x>
- Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, 7(2), 336–353. <https://doi.org/10.1037/1528-3542.7.2.336>

- Fang, S. P., Tzeng, O. J. L., & Alva, L. (1981). Intralanguage vs. interlanguage Stroop effects in two types of writing systems. *Memory & Cognition*, 9(6), 609–617. <https://doi.org/10.3758/bf03202355>
- Foa, E. B., Feske, U., Murdock, T. B., Kozak, M. J., & McCarthy, P. (1991). Processing of threat-related information in rape victims. *Journal of Abnormal Psychology*, 100(2), 156–162. <https://doi.org/10.1037/0021-843x.100.2.156>
- Frings, C., Englert, J., Wentura, D., & Bermeitinger, C. (2010). Decomposing the emotional Stroop effect. *Quarterly Journal of Experimental Psychology*, 63(1), 42–49. <https://doi.org/10.1080/17470210903156594>
- Gerhand, S. J., Deręowski, J. B., & McAllister, H. (1995). Stroop phenomenon as a measure of cognitive functioning of bilingual (Gaelic/English) subjects. *British Journal of Psychology*, 86(1), 89–92. <https://doi.org/10.1111/j.2044-8295.1995.tb02547.x/>
- Gray, J. R., Chabris, C. F., & Braver, T. S. (2003). Neural mechanisms of general fluid intelligence. *Nature Neuroscience*, 6(3), 316–322. <https://doi.org/10.1038/nn1014>
- Groot, A. M. D., Delmaar, P., & Lupker, S. J. (2000). The processing of interlexical homographs in translation recognition and lexical decision: Support for non-selective access to bilingual memory. *The Quarterly Journal of Experimental Psychology A*, 53(2), 397–428. <https://doi.org/10.1080/027249800390547>
- Gunnerud, H. L., ten Braak, D., Reikerås, E. K. L., Donolato, E., & Melby-Lervåg, M. (2020). Is bilingualism related to a cognitive advantage in children? A systematic review and meta-analysis. *Psychological Bulletin*. <https://doi-org.ezproxy.tlu.edu/10.1037/>
- Hartanto, A., & Yang, H. (2019). Does early active bilingualism enhance inhibitory control and monitoring? A propensity-matching analysis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 45(2), 360–378. <https://doi-org.ezproxy.tlu.edu/10.1037/xlm000058>

- Henik, A., & Tzelgov, J. (1982). Is three greater than five: The relation between physical and semantic size in comparison tasks. *Memory & Cognition*, *10*(4), 389–395. <https://doi.org/10.3758/bf03202431>
- Hernandez, A. E., & Li, P. (2007). Age of acquisition: Its neural and computational mechanisms. *Psychological Bulletin*, *133*(4), 638–650. <https://doi.org/10.1037/0033-2909.133.4.638>
- Hernandez, A. E., & Li, P. (2007). Age of acquisition: Its neural and computational mechanisms. *Psychological Bulletin*, *133*(4), 638–650. <https://doi.org/10.1037/0033-2909.133.4.638>
- Hilchey, M. D., & Klein, R. M. (2011). Are there bilingual advantages on nonlinguistic interference tasks? Implications for the plasticity of executive control processes. *Psychonomic Bulletin & Review*, *18*(4), 625–658. <https://doi.org/10.3758/s13423-011-0116-7>
- Hodgson, T. L., Parris, B. A., Gregory, N. J., & Jarvis, T. (2009). The saccadic Stroop effect: Evidence for involuntary programming of eye movements by linguistic cues. *Vision Research*, *49*(5), 569–574. <https://doi.org/10.1016/j.visres.2009.01.001>
- Hu, Y., Kang, X., & Mao, R. (2022). The Languages Impact on the Stroop Effect: Comparison in Chinese and English. *Advances in Social Science, Education and Humanities Research*. <https://doi.org/10.2991/assehr.k.211220.159>
- Hu, Y., Kang, X., & Mao, R. (2022). The Languages Impact on the Stroop Effect: Comparison in Chinese and English. *Advances in Social Science, Education and Humanities Research*. <https://doi.org/10.2991/assehr.k.211220.159>
- Incera, S., & McLennan, C. T. (2017). Bilingualism and age are continuous variables that influence executive function. *Aging, Neuropsychology, and Cognition*, *25*(3), 443–463. <https://doi.org/10.1080/13825585.2017.1319902>

- James R. Schmidt, Robert J. Hartsuiker, & Jan de Houwer. (2018). Interference in Dutch–French Bilinguals : Stimulus and Response Conflict in Intra- and Interlingual Stroop. *Le Centre Pour La Communication Scientifique Directe - HAL - Diderot*. <https://hal-univ-bourgogne.archives-ouvertes.fr/hal-01985154>
- Jared, D., & Kroll, J. F. (2001). Do Bilinguals Activate Phonological Representations in One or Both of Their Languages When Naming Words? *Journal of Memory and Language*, 44(1), 2–31. <https://doi.org/10.1006/jmla.2000.2747>
- Kahneman, D. (1973). *Attention and effort* (Vol. 1063). Englewood Cliffs, NJ: Prentice-Hall.
- Kar BR, Khare V, Dash T. Bilingualism and Cognitive Control: Is bilingualism a Cognitive Advantage? In Mishra R. K.& Srinivasan N., *Language and Cognition: State of the Art*. Munich: Lincom Europa. 2011.
- Kerkhofs, R., Dijkstra, T., Chwilla, D. J., & de Bruijn, E. R. (2006). Testing a model for bilingual semantic priming with interlingual homographs: RT and N400 effects. *Brain Research*, 1068(1), 170–183. <https://doi.org/10.1016/j.brainres.2005.10.087>
- Khare, V., Verma, A., Kar, B. R., Srinivasan, N., & Brysbaert, M. (2013). Bilingualism and the increased attentional blink effect: evidence that the difference between bilinguals and monolinguals generalizes to different levels of second language proficiency. *Psychological Research-Psychologische Forschung*, 77(6), 728–737. <https://doi.org/10.1007/s00426-012-0466-4>
- Klein, G. (1964). Semantic Power Measured through the Interference of Words with Color-Naming. *American Journal of Psychology*, 77(4), 576. <https://doi.org/10.2307/1420768>
- Kousaie, S., & Phillips, N. A. (2012). Ageing and bilingualism: Absence of a “bilingual advantage” in Stroop interference in a nonimmigrant sample. *Quarterly Journal of Experimental Psychology*, 65(2), 356–369. <https://doi.org/10.1080/17470218.2011.604788>

- Kroll, J. F., & Bialystok, E. (2013). Understanding the consequences of bilingualism for language processing and cognition. *Journal of Cognitive Psychology*, 25(5), 497–514. <https://doi.org/10.1080/20445911.2013.799170>
- Kroll, J., & Stewart, E. (1994). Category Interference in Translation and Picture Naming: Evidence for Asymmetric Connections Between Bilingual Memory Representations. *Journal of Memory and Language*, 33(2), 149–174. <https://doi.org/10.1006/jmla.1994.1008>
- Lansbergen, M., Kenemans, J. L., & Van Engeland, H. (2007). Stroop interference and attention-deficit/hyperactivity disorder: A review and meta-analysis. *Neuropsychology (Journal)*, 21(2), 251–262. <https://doi.org/10.1037/0894-4105.21.2.251>
- Larsen, R. W., Mercer, K. A., & Balota, D. A. (2006). Lexical characteristics of words used in emotional Stroop experiments. *Emotion*, 6(1), 62–72. <https://doi.org/10.1037/1528-3542.6.1.62>
- Lee, T. M. C., & Chan, C. C. H. (2000). Stroop Interference in Chinese and English. *Journal of Clinical and Experimental Neuropsychology*, 22(4), 465–471. [https://doi.org/10.1076/1380-3395\(200008\)22:4;1-0;ft465](https://doi.org/10.1076/1380-3395(200008)22:4;1-0;ft465)
- Lee, T. M., & Chan, C. T. (2000). Stroop Interference in Chinese and English. *Journal of Clinical and Experimental Neuropsychology*, 22(4), 465–471. [https://doi.org/10.1076/1380-3395\(200008\)22:4;1-0;ft465](https://doi.org/10.1076/1380-3395(200008)22:4;1-0;ft465)
- Libben, M. R., & Titone, D. A. (2009). Bilingual lexical access in context: Evidence from eye movements during reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 35(2), 381–390. <https://doi.org/10.1037/a0014875>
- Linck, J. A., Kroll, J. F., & Sunderman, G. (2009). Losing Access to the Native Language While Immersed in a Second Language: Evidence for the Role of Inhibition in Second-

Language Learning. *Psychological Science*, 20(12), 1507–1515.  
<https://doi.org/10.1111/j.1467-9280.2009.02480.x>

Luk, G., De Sa, E., & Bialystok, E. (2011). Is there a relation between onset age of bilingualism and enhancement of cognitive control? *Bilingualism: Language and Cognition*, 14(4), 588–595. <https://doi.org/10.1017/s1366728911000010>

MacLeod, C. (2015). The Stroop Effect. *Springer EBooks*, 1–6. [https://doi.org/10.1007/978-3-642-27851-8\\_67-1](https://doi.org/10.1007/978-3-642-27851-8_67-1)

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin*, 109(2), 163–203. <https://doi.org/10.1037/0033-2909.109.2.163>

MacLeod, C., & MacDonald, P. A. (2000). Interdimensional interference in the Stroop effect: uncovering the cognitive and neural anatomy of attention. *Trends in Cognitive Sciences*, 4(10), 383–391. [https://doi.org/10.1016/s1364-6613\(00\)01530-8](https://doi.org/10.1016/s1364-6613(00)01530-8)

Magiste, E. (1984). Stroop tasks and dichotic translation: The development of interference patterns in bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 10(2), 304–315. <https://doi.org/10.1037/0278-7393.10.2.304>

Marcel, A. J. (1983). Conscious and unconscious perception: Experiments on visual masking and word recognition. *Cognitive Psychology*, 15(2), 197–237. [https://doi.org/10.1016/0010-0285\(83\)90009-9](https://doi.org/10.1016/0010-0285(83)90009-9)

McKenna, F. P., & Sharma, D. (2004). Reversing the Emotional Stroop Effect Reveals That It Is Not What It Seems: The Role of Fast and Slow Components. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 30(2), 382–392. <https://doi.org/10.1037/0278-7393.30.2.382>

- McNally, R. J., Kaspi, S. P., Riemann, B. C., & Zeitlin, S. B. (1990). Selective processing of threat cues in posttraumatic stress disorder. *Journal of Abnormal Psychology, 99*(4), 398–402. <https://doi.org/10.1037/0021-843x.99.4.398>
- Mechelli, A., Crinion, J. T., Noppeney, U., O'Doherty, J., Ashburner, J., Frackowiak, R. S., & Price, C. J. (2004). Structural plasticity in the bilingual brain. *Nature, 431*(7010), 757. <https://doi.org/10.1038/431757a>
- Melara, R. D., & Algom, D. (2003). Driven by information: A tectonic theory of Stroop effects. *Psychological Review, 110*(3), 422–471. <https://doi.org/10.1037/0033-295x.110.3.422>
- Milham, M. P., Banich, M. T., Claus, E. D., & Cohen, N. J. (2003). Practice-related effects demonstrate complementary roles of anterior cingulate and prefrontal cortices in attentional control☆ ☆This study was supported by the Beckman Institute for Advanced Science and Technology at the University of Illinois, Urbana-Champaign; Carle Clinic, Urbana, Illinois; and NIMH MD/PhD predoctoral National Research Service Award provided support to M.P.M. (MH12415-01). *NeuroImage, 18*(2), 483–493. [https://doi.org/10.1016/s1053-8119\(02\)00050-2](https://doi.org/10.1016/s1053-8119(02)00050-2)
- Ning, R. (2021). How language proficiency influences stroop effect and reverse-stroop effect: A functional magnetic resonance imaging study. *Journal of Neurolinguistics, 60*, 101027. <https://doi.org/10.1016/j.jneuroling.2021.101027>
- Ovaysikia, S., Tahir, K. A., Chan, J. Y., & DeSouza, J. F. X. (2011). Word Wins Over Face: Emotional Stroop Effect Activates the Frontal Cortical Network. *Frontiers in Human Neuroscience, 4*. <https://doi.org/10.3389/fnhum.2010.00234>
- Paap, K. R., & Greenberg, Z. I. (2013). There is no coherent evidence for a bilingual advantage in executive processing. *Cognitive Psychology, 66*(2), 232–258. <https://doi.org/10.1016/j.cogpsych.2012.12.002>

- Pathak, L. S., & Pathak, P. (2022). Bilingual Stroop Effect in High and Low Proficient Nepali-English Bilinguals. *Nepalese Linguistics*, 128–136. <https://doi.org/10.3126/nl.v35i01.46570>
- Paulmann, S., Elston-Güttler, K. E., Gunter, T. C., & Kotz, S. A. (2006). Is bilingual lexical access influenced by language context? *NeuroReport*, 17(7), 727–731. <https://doi.org/10.1097/01.wnr.0000214400.88845.fa>
- Posner, M. I. (1980). Orienting of Attention. *Quarterly Journal of Experimental Psychology*, 32(1), 3–25. <https://doi.org/10.1080/00335558008248231>
- Posner, M. I. (1994). Attention: the mechanisms of consciousness. *Proceedings of the National Academy of Sciences of the United States of America*, 91(16), 7398–7403. <https://doi.org/10.1073/pnas.91.16.7398>
- Posner, M. I., & Petersen, S. E. (1990). The Attention System of the Human Brain. *Annual Review of Neuroscience*, 13(1), 25–42. <https://doi.org/10.1146/annurev.ne.13.030190.000325>
- Potter, M. C., So, K. F., Eckardt, B. V., & Feldman, L. B. (1984). Lexical and conceptual representation in beginning and proficient bilinguals. *Journal of Verbal Learning and Verbal Behavior*, 23(1), 23–38. [https://doi.org/10.1016/s0022-5371\(84\)90489-4](https://doi.org/10.1016/s0022-5371(84)90489-4)
- Preston, M. S., & Lambert, W. E. (1969). Interlingual interference in a bilingual version of the stroop color-word task. *Journal of Verbal Learning and Verbal Behavior*, 8(2), 295–301. [https://doi.org/10.1016/s0022-5371\(69\)80079-4](https://doi.org/10.1016/s0022-5371(69)80079-4)
- Reinholdt-Dunne, M. L., Mogg, K., & Bradley, B. P. (2009). Effects of anxiety and attention control on processing pictorial and linguistic emotional information. *Behaviour Research and Therapy*, 47(5), 410–417. <https://doi.org/10.1016/j.brat.2009.01.012>

- Rodriguez-Fornells, A., De Diego Balaguer, R., & Münte, T. F. (2006). Executive Control in Bilingual Language Processing. *Language Learning*, 56, 133–190. <https://doi.org/10.1111/j.1467-9922.2006.00359.x>
- Rodriguez-Fornells, A., Van der Lugt, A., Rotte, M., Britti, B., Heinze, H. J., & Munte, T. F. (2005). Second language interferes with word production in fluent bilinguals: Brain potential and functional imaging evidence. *Journal of Cognitive Neuroscience*, 17, 422–433.
- Rosselli, M. (2000). The stroop test in spanish-english bilinguals. *Archives of Clinical Neuropsychology*, 15(8), 692–693. [https://doi.org/10.1016/s0887-6177\(00\)80077-3](https://doi.org/10.1016/s0887-6177(00)80077-3)
- Rosselli, M., Ardila, A., Santisi, M. N., Arecco, M. D. R., Salvatierra, J., Conde, A., & Lenis, A. B. (2002). Stroop effect in Spanish–English bilinguals. *Journal of the International Neuropsychological Society*, 8(6), 819–827. <https://doi.org/10.1017/s1355617702860106>
- Singh, N., & Mishra, R. K. (2012). Does language proficiency modulate oculomotor control? Evidence from Hindi–English bilinguals. *Bilingualism: Language and Cognition*, 15(4), 771–781. <https://doi.org/10.1017/s1366728912000065>
- Singh, N., & Mishra, R. K. (2013). Second language proficiency modulates conflict-monitoring in an oculomotor Stroop task: evidence from Hindi-English bilinguals. *Frontiers in Psychology*, 4. <https://doi.org/10.3389/fpsyg.2013.00322>
- Singh, N., & Mishra, R. K. (2015). Unintentional Activation of Translation Equivalents in Bilinguals Leads to Attention Capture in a Cross-Modal Visual Task. *PLOS ONE*, 10(3), e0120131. <https://doi.org/10.1371/journal.pone.0120131>
- Smith, M. J., & Kirsner, K. (1982). Language and Orthography as Irrelevant Features in Colour-Word and Picture-Word Stroop Interference. *The Quarterly Journal of*

<https://doi.org/10.1080/14640748208400864>

Spreen, O., & Strauss, E. (1991). A compendium of neuropsychological tests: administration, norms, and commentary. *Choice Reviews Online*, 29(04), 29–2400.

<https://doi.org/10.5860/choice.29-2400>

Stasenko, A., Matt, G. E., & Gollan, T. H. (2017). A relative bilingual advantage in switching with preparation: Nuanced explorations of the proposed association between bilingualism and task switching. *Journal of Experimental Psychology: General*, 146(11), 1527–1550. <https://doi-org.ezproxy.tlu.edu/10.1037/xge0000340.supp> (Supplemental)

Stroop, J. R. (1992). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 18(6), 643–662. <https://doi.org/10.1037/h0054651>

Suarez, P. A., Gollan, T. H., Heaton, R., Grant, I., & Cherner, M. (2014). Second-Language Fluency Predicts Native Language Stroop Effects: Evidence from Spanish–English Bilinguals. *Journal of the International Neuropsychological Society*, 20(3), 342–348.

<https://doi.org/10.1017/s1355617714000058>

Sumiya, H., & Healy, A. F. (2004). Phonology in the bilingual Stroop effect. *Memory & Cognition*, 32(5), 752–758. <https://doi.org/10.3758/bf03195865>

Tao, L., Marzecová, A., Taft, M., Asanowicz, D., & Wodniecka, Z. (2011). The Efficiency of Attentional Networks in Early and Late Bilinguals: The Role of Age of Acquisition. *Frontiers in Psychology*, 2. <https://doi.org/10.3389/fpsyg.2011.00123>

Traxler, M. J. (2011). *Introduction to Psycholinguistics*. Wiley-Blackwell.

Tzelgov, J., Henik, A., & Leiser, D. (1990). Controlling Stroop interference: Evidence from a bilingual task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 16(5), 760–771. <https://doi.org/10.1037/0278-7393.16.5.760>

- Van Hell, J. G., & Dijkstra, T. (2002). Foreign language knowledge can influence native language performance in exclusively native contexts. *Psychonomic Bulletin & Review*, 9(4), 780–789. <https://doi.org/10.3758/bf03196335>
- Van Heuven, W. J. B., Conklin, K., Coderre, E. L., Guo, T., & Dijkstra, T. (2011). The Influence of Cross-Language Similarity on within- and between-Language Stroop Effects in Trilinguals. *Frontiers in Psychology*, 2. <https://doi.org/10.3389/fpsyg.2011.00374>
- Van Heuven, W. J., Schriefers, H., Dijkstra, T., & Hagoort, P. (2008). Language Conflict in the Bilingual Brain. *Cerebral Cortex*, 18(11), 2706–2716. <https://doi.org/10.1093/cercor/bhn030>
- von Bastian, C. C., Souza, A. S., & Gade, M. (2016). No evidence for bilingual cognitive advantages: A test of four hypotheses. *Journal of Experimental Psychology: General*, 145(2), 246–258. <https://doi.org/10.1037/xge0000120>
- Wang, A. (2021). Numerical Processing in the Stroop Task of Working Memory. *OALib*. <https://doi.org/10.4236/oalib.1107344>
- Wang, R., Fan, X., Liu, C., & Cai, Z. G. (2014). Cognitive control and word recognition speed influence the Stroop effect in bilinguals. *International Journal of Psychology*, 51(2), 93–101. <https://doi.org/10.1002/ijop.12115>
- Williams, J. C., Mathews, A., & Macleod, C. (1996). The emotional Stroop task and psychopathology. *Psychological Bulletin*, 120(1), 3–24. <https://doi.org/10.1037/0033-2909.120.1.3>
- Wyble, B. P., Sharma, D., & Bowman, H. (2008). Strategic regulation of cognitive control by emotional salience: A neural network model. *Cognition & Emotion*, 22(6), 1019–1051. <https://doi.org/10.1080/02699930701597627>

- Yow, W. Q., & Li, X. (2015). Balanced bilingualism and early age of second language acquisition as the underlying mechanisms of a bilingual executive control advantage: why variations in bilingual experiences matter. *Frontiers in Psychology*, 6. <https://doi.org/10.3389/fpsyg.2015.00164>
- Yu, Z., & Schwieter, J. W. (2018). Recognizing the Effects of Language Mode on the Cognitive Advantages of Bilingualism. *Frontiers in Psychology*, 9. <https://doi.org/10.3389/fpsyg.2018.00366>
- Zied, K. M., Phillipe, A., Karine, P., Valerie, H., Ghislaine, A., Arnaud, R., & Didier, L. C. (2004). Bilingualism and adult differences in inhibitory mechanisms: evidence from a bilingual stroop task. *Brain and Cognition*, 54(3), 254–256. <https://doi.org/10.1016/j.bandc.2004.02.036>