Exploring immediate memory for lists of items by manipulating the inter-item intervals

Priya Kulasekhara Varma

Submitted in accordance with the requirements for the degree of Doctor of Philosophy

The University of Leeds

School of Psychology

April, 2025

The candidate confirms that the work submitted is her own, except where work which has formed part of jointly-authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others. This copy has been supplied on the understanding that it is copyright material and that no quotation from the thesis may be published without proper acknowledgement.

Priya Varma designed the experiments and conducted all data collection and analysis for this chapter with the supervision of Dr Denis McKeown and Dr Jean Francois Delvenne. The manuscripts were written by Priya Varma with guidance on drafts from Dr Denis McKeown and Dr Jean Francois Delvenne

Acknowledgements

First and foremost, I would like to thank my primary supervisor, Dr Denis McKeown, as he was one of the main reasons that this piece of work came into existence. His knowledge and expertise in this field and his valuable guidance cannot be overstated. As we address our mentors in India with respect, ‘Sir, I am immensely grateful for your encouragement and never ending support throughout the years’. My thanks also goes to my co-supervisor, Dr Jelena Havelka, for her advice and guidance. A special thanks also goes to Dr Melanie Burke for her guidance as a Postgraduate Tutor and for arranging for an alternate supervisor in record time. Thank you to the Leeds International Research Scholarship program that provided the funding for my PhD.

Thanks to all the participants who took part in my studies. Thank you to all the psychology under graduates who took time out of their busy student lives to participate in my research. My thanks also goes to my fellow postgraduate research students, especially Kristian and Emily who were amazing motivators during times when I felt I could never get this done. Special thanks to Emily for making the conference trip to Canada so memorable and for taking such good care of me and my broken leg!

This thesis would not have been possible if not for Dr Jean Francois Delvenne who very kindly agreed to look over the final few drafts of my thesis and recommended amendments. I truly appreciate his time and expertise.

I am immensely grateful for the support of my husband, Susheel, who was there with me from the beginning and put up with me patiently through all my ups and downs, my mood swings, my panic attacks, my failures as well as successes. Thank you also for helping me with MATLAB and countless other parts of my thesis when I felt completely hopeless. I may not admit it openly but I genuinely could not have done this without you. I am also forever grateful to my family; Chit, Am, Mon and Sunder for always being there at the end of a phone to give me moral support and encouragement. They knew before I did that I could do this.

My thesis is dedicated to my father whose dream it was to see me complete my PhD. Thank you Accha, for always being my cheerleader and always believing in me. I think you may be more relieved than I am that this is finally over. Thank you Amma for watching over me from above.

‘*Great things don’t come from comfort zones’*. - Roy T. Bennett, The Light in the Heart.

I do not know whether this piece of work is a ‘great thing’ – one can only hope; but this was definitely out of my comfort zone. It challenged me in ways I never imagined. Thanks to everyone who helped in the making of my thesis.

Abstract

Psychological time, unlike physical time, is believed to be ‘compressive’ in the sense that the mental representations of a series of events may be internally arranged with ever decreasing inter-event spacing (looking back from the most recently encoded event). If this is true, the record within immediate memory of recent events is severely temporally distorted. Although this notion of temporal distortion of the memory record is captured within some theoretical accounts of human forgetting, notably temporal distinctiveness accounts, the way in which the fundamental nature of the distortion underpins memory and forgetting broadly is barely recognised or at least directly investigated. The intention here was to manipulate the spacing of items for recall in order to ‘reverse’ this supposed natural compression within the encoding of the items. The experimental test of this idea was to compare recall performance using differing schedules of presentation of lists of words (logarithmically expanding, contracting or fixed irregular inter-item spacing). Statistically significant benefits of temporal isolation were observed, with the contracting word series (which we may think of as reversing the natural compression within the mental representation of the word list) showing highest performance (Experiment 1); even when they were controlled for active maintenance processes like attentional refreshing and articulatory rehearsal (Experiment 2 and 3). Further experimental tests suggested that an encoding benefit for the contracting series did not rely simply on providing an opportunity for active verbal maintenance early in the word sequence; for example, the pattern of performance improvement was observed using Chinese characters rather than words (Experiment 4). It was seen that, in addition to temporal isolation of items, a short retention interval (as opposed to no retention interval or a long retention interval) is beneficial for memory (Experiment 5). Finally, benefits of temporal isolation of items were also seen for colour memory (Experiment 6). Additionally, it was seen that benefits of a logarithmically contracting series (in time) were mostly observed only for free recall and not for serial recall. Together the outcomes of the experiments broadly support the notion of temporal compression within the encoding of series of items within immediate memory.

Contents

Figures

Tables

Abbreviations

η_{p2}	partial eta squared, Effect size for ANOVA analysis
ANOVA	Analysis of variance
CRP	Conditional Response Probability
d	Cohen's measure of effect size for comparing two sample means
d'	Discriminability, a measure of sensitivity in signal detection theory
ISI	Inter-stimulus interval
M	Mean
Min	Minutes
Ms	Milliseconds
P	Probability
RAS	Recognition accuracy score
RI	Retention interval
S	Seconds
SD	Standard Deviation
SAM	Search of Associative Memory
SIMPLE	Scale-independent memory, perception, and learning model
TBRS	Time based resource sharing model
Z	z score

Chapter 1 - Introduction and Literature Review

1.1 General Introduction

This chapter will set the context of the present study or set of experiments within contemporary memory theory, focusing particularly on encoding and retrieval in the short term (of the order of seconds or minutes). Specifically, theories of forgetting (including decay and interference), refreshing and time based accounts of memory and forgetting will be discussed. It will also consider selected relevant literature on memory for sequences of items. Studies investigating short-term memory for lists of items have largely concentrated on relevant studies of serial recall that have been inspired by the Baddeley & Hitch model (1974). However, time-based accounts of memory do not necessarily adhere to this model and therefore, there is a definite scope for new research which investigates encoding and retrieval of items and temporal spacing. Finally, this chapter will introduce the rationale for the present series of experiments.

1.2 Contemporary memory accounts of encoding and retrieval

In this section, the major contemporary memory accounts for short-term memory or memory as a temporal record of the immediate past will be introduced and discussed in detail. The different theories will look at memory as a whole, as well as, in terms of encoding and retrieval separately. Broadly, there are two sets of theories that have been proposed and they are fundamentally different from each other with regards to their perception of the role of time in memory. The time-based theories, by and large, consider time to be responsible for decline in memory, whereas, the event-based theories think of the passage of time as being a mere co-occurrence and any effects that time may have are only secondary to the more important and primary influences of interference. Within the time-based theories, there is no happy consensus as there are different ideas as to how time might influence memory and there are, again, two major ideas discussed here. Time-based decay is one of the widely researched, but controversial, ideas which suggest that memory traces become weaker and are lost over time. The second and more recent idea comprises the temporal distinctiveness or temporal isolation accounts which propose that memory of any item is contingent on its relative position in time during presentation- how far or near the item is (temporally) in relation to other items that are also presented. Similarly, the event-based theories also propose different types of interference that may influence memory; proactive and retroactive interference, novelty-based interference, similarity-based interference etc. But this section will limit its review to studies on proactive and retroactive interference as they are the most relevant to the present series of experiments.

1.2.1 Forgetting

Over a century ago, Ebbinghaus (1885) pioneered scientific research on memory using himself as a subject. He concluded that memories decline as a power function of time. And, whilst memory decline is initially very rapid, other factors, such as how the information is presented or rehearsed, influence its recall. This became known as the ‘Ebbinghaus forgetting curve’ which inspired many of the current, prominent and established theories of forgetting. However, the question of why forgetting occurs over the short term is still heavily debated within the literature, where the major question continues to be whether memory traces simply decay over time or whether forgetting is due to alternative processes (Ricker, Vergauwe & Cowan, 2016)

The term ‘short-term memory’ in and of itself implies that some information is lost or disappears in a short amount of time and inherently gives credibility to the concept of forgetting. It is this loss of information that has long concerned memory researchers. The processes underlying memory are complex and therefore, cognitive scientists and psychologists in general, have made the necessary distinction between encoding, storage (or maintenance) and retrieval and this can help simplify the understanding of it (Melton, 1963). Encoding refers to the initial step in the memory process by which the sensory information received is converted into a form that can then be stored in the brain for later retrieval. This stage is important because there will be no memory or information to retrieve later (forgetting is inevitable) if the sensory information that was presented was not even perceived and /or converted appropriately to be stored in the brain for later use. This stage could also be thought of as the stage where to-be-stored memory traces are created. Storage is the next crucial step in this process and can be described as the stabilising or retaining of information that has been created during encoding through a process called consolidation. Retrieval is the process by which memory traces that have been stored in the brain are ‘called to the fore’ or utilized in recognition, recall or any other purpose like transfer (Melton, 1963). For the purposes of this review, the different accounts of forgetting will be discussed keeping these memory processes in mind. The 1950s and 1960s saw the emergence of two competing views to explain memory loss or forgetting – decay (Brown, 1958) and interference (Keppel & Underwood, 1962; Waugh & Norman, 1968).

1.2.2 Trace decay theories of forgetting

Arguably, the most recognised theory of forgetting in immediate memory is time-based decay. Decay has been described as the process by which memory traces lose activation with the passage of time (Brown, 1958). Just like Ebbinghaus (1885), decay theorists posit that forgetting is a consequence of time; as time passes, the memory trace simply fades away. Brown (1958) produced evidence for the idea that decay could occur in ‘immediate’ memory (memory over a period of a few seconds) while most other researchers were concerned with much longer delays (see Ricker, Vergauwe, & Cowan, 2016). His experiments refuted the assumptions of interference theorists at the time by showing that when there was an empty delay, memory performance was almost at ceiling level but when it was filled with sufficiently different distractor items that were thought to cause little or no interference, it resulted in significant forgetting (Brown, 1958). Brown conducted a series of experiments to test the decay hypothesis where participants were presented with pairs (at least one, and up to four) of consonants and were asked to recall them. In the first condition, there was only a 5s unfilled gap before the recall; in the other condition, this gap was ‘filled’ with numbers that participants had to read aloud. The broad pattern of results revealed that hardly any forgetting had occurred (except when more pairs of letters were presented) when the retention interval was unfilled. However, significant forgetting took place when participants were engaged in a digit-reading task which interfered with verbal rehearsal of the memoranda. Therefore, Brown concluded that decay occurs when rehearsal is prevented. Peterson and Peterson (1959) conducted a similar study to Brown’s (1958); however, this time they varied the time before the recall (3, 6, 9, 12, 15 or 18s in length). Participants were asked to recall trigrams (meaningless three-consonant syllables e.g. XRQ) and count backwards in threes or fours before recall. The idea was that counting backwards will prevent active rehearsal of the trigram with little interference. They had six different conditions of the delay between presentation of to-be-remembered item and recall, otherwise referred to as retention interval (RI) which included 3, 6, 9, 12, 15 and 18s. When tested after 3s of counting, recall was approximately 80% whereas when tested after counting for 18s, recall decreased to approximately 10% (Peterson & Peterson, 1959). This finding has provided further evidence for decay in short term memory when rehearsal is prevented. The methodology used in these experiments became known as the Brown-Peterson technique/task (eg., Quinlan, Neath, & Surprenant, 2015), where a distractor task is introduced within the memory retention interval, and this technique is now a classical measure of short-term memory. The Brown-Peterson paradigm (Peterson & Peterson, 1959) helped to investigate the rate at which decay occurs and their results supported decay in that there was a steady decrease in the recall with increase in the delay to recall. This paper is considered by some memory theorists (Ricker et al., 2016, p. 1) as a 'landmark article that marked a shift in memory research during the early stages of the cognitive revolution'.

Another early study favouring the role of decay was the study by Wingfield & Byrnes (1972). Their study does support decay but does not introduce any distractor activity to prevent verbal rehearsal. Instead, they introduced a clever technique to delay recall in one condition more than another, and in this more delayed recall condition, forgetting occurred more. The authors adapted a technique invented by Broadbent (1958) called the split-span task where participants were presented with auditory information that arrives at the ears simultaneously through different channels. The stimuli they used was the same as Broadbent, lists of digits. However, they separated the channels by voice, a male versus female voice. The lists were presented to both ears through headphones at a constant rate and they also varied the recall conditions, namely, either successive report (channel-wise report) in which the participants recalled all the digits heard in the male voice first and then the digits heard in the female voice; or pair-by-pair report in which participants recalled the digits in the order that it was heard i.e. digits in the first simultaneous pair (male and female voice) followed by digits in the second simultaneous pair and so on. The study showed that channel-wise recall was superior to pair-wise recall with respect to both overall accuracy and also total time taken for recall. Wingfield & Byrnes (1972) explained this advantage that the channel-wise recall had using the decay theory simply because the pair-wise recall occurred later. The significance of this study at the time was that they were the only ones who measured the latency of responses (response time). This allowed for them to hypothesise that pair-wise recall happened later than channel-wise recall (although it was not entirely clear as to why participants chose to recall channel-wise rather than pair-wise) and it is this latency that leads to decrease in accuracy, hence providing evidence for decay theory. Thus, it seems that the difference in performance between these two report strategies is directly attributable to differences in time in storage - the longer the time spent in storage without rehearsal or repetition, the weaker the memory trace gets. As a consequence, a difficulty in retrieval is seen despite there being no observable encoding difficulties and other intervening events were held constant.

Support for decay in memory research comes from various sources. The concept of decay is included (implicitly or even explicitly in some cases) in many influential models (Atkinson & Shiffrin, 1968; Baddeley, 1986; Barrouillet & Camos, 2012; Broadbent, 1958; Sperling, 1960). One of the most successful models which asserted the presence of decay in short-term memory was Baddeley (1986)'s multi-component model and particularly, the modified version has been widely used by clinicians and researchers in other fields (Ricker et al., 2016). The multi-component model was composed of three main components; the central executive which acts as supervisory system and controls the flow of information from and to the other systems: the phonological loop and the visuo-spatial sketchpad. The phonological loop stores verbal content, whereas the visuo-spatial sketchpad caters to visuo-spatial data. Baddeley later added a third storage system to his model, the episodic buffer (Baddeley, 2000) which is a limited-capacity system that acts as a link between the visual, spatial and verbal domains along with chronological ordering. The description of the phonological loop was heavily reliant on decay. The phonological loop is a limited-capacity system from which memory traces decay or they are lost unless there is some form of rehearsal. The discovery of word length effect (Baddeley, Thomson, & Buchanan, 1975) provided further evidence for time-based decay when they found that more number of short length words could be remembered and it was not the number of words but the time it took to articulate the words that mattered. Therefore, the phonological loop was found to be time-limited and once that limit had been reached, memory traces are lost from the loop. The verbal component of this model explicitly relied on time as the causal factor for the loss of memory traces. The visuo-spatial component, however, only utilised decay implicitly to explain forgetting (Ricker et al., 2016). The decay described here occurs in the storage stage of memory processing but a closer look reveals that decay plays a crucial role in encoding as well since decay is a necessary precursor to encoding (*see functional decay, Altmann, 2002 in section 1.2.3).*

One of the more recent models is the Time-Based Resource Sharing (TBRS) model (Barrouillet & Camos, 2012). They suggest that decay of memory traces occurs unless repeatedly attended to or 'refreshed'. They proposed this to be true for all types of stimuli including verbal and non-verbal stimuli like visual, spatial, auditory etc. According to this model, if attention is focussed on other activities after a stimulus has been presented, then the memory trace for the stimulus decays until the attention is refocussed on the stimulus (or the memory is refreshed). The strength of the memory trace then relied on the frequent refreshing of the same and also, on the fact that too much time had not elapsed before refreshing occurred causing the trace to decay significantly. So, although this model did not prescribe to the assumption that simply increasing retention intervals will lead to poorer recall, it suggested that time-based trace decay does occur but can be prevented by attending to the memory trace.

Another source of support for trace decay comes from studies specifically addressing decay (McKeown & Mercer, 2012; Mercer & McKeown, 2014; Ricker & Cowan, 2010) using stimuli that are difficult to rehearse like auditory tones and unconventional visual characters to circumvent the problem of rehearsal without filling the delay gaps. These studies revealed decay in short-term non-verbal memory. An early study by Harris (1952), used non-verbal stimuli that would be difficult to verbalise - auditory tones with suble difference in frequency. He varied the retention interval between a target tone and a probe tone from 0.1 to 25s and found that as the retention intervals increased, the accuracy of recognising matched tones was poorer. A later study conducted by McKeown & Mercer (2012) using complex tones to be recognised over extended retention intervals demonstrated that auditory memory remained strong over extended retention intervals (RIs). Having said that, they also found that performance was better at short (1, 2, or 4s) than long (8, 16, or 32s) RIs for this memory for complex tones task. Hence, they also came to similar conclusions. Berman, Jonides, & Lewis (2009) used the recent negative probe technique and found little evidence for trace decay. The recent negative probe technique is where after being shown a list of to-be-remembered stimuli, a probe is shown that is either the same as one of the stimuli in the current list (positive), or same as one of the stimuli shown in the previous list (recent negative) or was a completely new stimulus (non-recent-negative); and subjects have to decide whether the probe was shown in the current list or not. However, Mercer & McKeown (2014), used a similar paradigm and found evidence for decay based on the passage of absolute time. Their results revealed slower responses when the probe matched a target in the previous trial. This indicatedthat the memory trace of the previously presented list was still lingering. Moreover, the amount of slowing could also indicate the extent to which it lingered. Controversially, extending the gap between trials did not reduce the influence of old trial memories, thus providing evidence against rapid decay. McKeown et al. (2014) concluded that there is an active form of memory that decays despite participants' attentional efforts to maintain memoranda, and this decay does not occur as rapidly as previously thought.

1.2.3 Decay and Interference

Keppel and Underwood (1962) challenged the trace decay explanation made by Brown (1958), and Peterson and Peterson (1959). In their experiments, they showed that forgetting might be due to proactive interference rather than decay. Interference is defined as *'the phenomenon in which the retrieval of a memory can be disrupted by the presence of related traces in memory'* (Baddeley, Eysenck & Anderson, 2009, p.198). Additionally, an important distinction is made between proactive interference (previously acquired knowledge interferes with current learning) and retroactive interference (acquisition of new information interferes with what has already been learnt). Keppel and Underwood (1962), in one of their experiments, presented participants with three letters displayed for 2s and then asked them to count backwards in threes after hearing a random number. Keppel and Underwood (1962) analysed their data by trial number and found that the performance declined as the number of trials increased. They concluded that this forgetting occurred due to interference from previous trials rather than decay. Further evidence supporting this view came from a study by Loess (1968). As interference largely depends on similarity, Loess (1968) presented participants with three words from the same semantic category (e.g. names of trees); after five trials, the category was changed. As expected, memory performance declined with the number of trials from the same category; however, when the category was changed, performance improved again.

The effects of proactive interference have been observed widely (Beaudry, Neath, Surprenant & Tehan, 2014). Empirical research examining memory has been dominated by experimental designs whereby participants receive multiple trials of having to learn and recall a list of items and their recall performance is averaged across all experimental trials (e.g. Brown et al., 2006; Neath & Crowder, 1996). In doing so, researchers can generate a large amount of data from a small group of participants. However, Underwood (1957) highlighted this as a flaw in this paradigm as when data are re-plotted as a function of the number of previous trials, recall ability progressively deteriorates. Therefore, the majority of memory research to date has been unable to side-step the effects of proactive interference on recall performance.

A study by Baddeley & Scott (1971) examining forgetting in immediate memory is an exception in empirical research to multiple-trial testing as it was designed to minimise or eliminate all forms of interference (retroactive, proactive and intra-sequence). Most notably, the study was able to avoid proactive interference by using a single trial design; as participants were only tested once, memory representations of prior experimental items were largely avoided. In fact, the conclusions of this study have been said to have dominated this field of research for three decades as it has been consistently used as evidence against an interference account of forgetting in favour of a trace decay model (Neath & Brown, 2012). Baddeley & Scott stated that, since they did observe forgetting in the 'single-trial' situation (where prior item interference is removed), then decay must be occurring. They tried to discount the other form of interference – retroactive – but their arguments were not fully convincing. Later, Neath & Brown (*see section 1.2.4*) propose that the data from the Baddeley & Scott experiment can be explained using a model of temporal distinctiveness as interference for an item is mostly determined by its neighbours.

Interestingly, a concept that integrates decay and interference is functional decay (Altmann, 2002) which Altmann suggests is an active process in order to reduce the interference of previous memory traces to the learning of new information, in other words, to reduce proactive interference. Decay refers to forgetting due to a gradual loss of the substrate of memory and although this has generally been assumed to be a passive process, it could well be an active removal of disused memories (Hardt, Nader, & Nadel, 2013). Altmann (2002) conducted a series of task-switching experiments where he demonstrated that in order to learn new tasks, it is necessary to actively remove the memory traces of the current task and that this process considerably slows down the encoding of the new task. He concluded that interference of previously learned material is a central constraint on cognitive control and hence, one has to actively 'forget' it. In another paper, Altmann & Trafton (2002) propose that memory for goals is maintained through rehearsal and refreshing and these processes were largely assumed to be implicit which will be discussed in more detail later (*see section 1.2.3*) in this review.

Short-term memory is also influenced and indeed enhanced by the time allowed for consolidation (Bayliss, Bogdanovs, & Jarrold, 2015; Jolicœur & Dell'Acqua, 1998). During an unfilled time interval (with no interference), memory consolidation may occur by utilising aforementioned strategies like rehearsal and refreshing. Therefore, it may be seen as an active process that works to strengthen a new memory trace so that it can be later remembered successfully (Dewar et al., 2014; Mercer, 2015). It can be argued, then, that sufficient temporal space must be allowed for this process to occur. Wixted (2004) made a good case for this as he drew attention to a forgetting law of Jost (end of the 19th century) which suggested that, with time, old encoded items within memory are less at risk of being lost or at risk of decay despite the lapse of time and the presence of successive interference. Intuitively, this idea that retroactive interference can be reduced by allowing for a temporal interval for the encoded memory trace to 'sink in' seems credible as over the years it has been backed up by empirical support. For instance, visual stimuli may suffer from rapid time based decay if there is reduced opportunity for consolidation (Knöchel et al., 2015). Bayliss et al. (2015) manipulated time after encoding for lists of consonants by introducing a distractor either immediately or following a delay (note that RI was held the same across the different conditions). They found that when the distractor was presented immediately after an item, the memory for that item was poorer than if a delay was given before the distractor activity. Hence, they demonstrated that this process of consolidation as well as time given for consolidation is important for successive recall of the item and may be independent of processes such as rehearsal and refreshing. Ricker & Cowan (2014) observed that providing short inter-stimulus intervals post-encoding gives little opportunity for consolidation and affected recall negatively. They concluded that "whether or not time-based forgetting will be observed in a working memory task is largely determined by the amount of time allowed for consolidation of working memory" (p. 427). At the same time, Ricker (2015) explained in a review paper that there is a lack of clarity as to the time needed for short-term consolidation or indeed whether or how it might differ from the more familiar 'encoding time' of the memory trace. From the above discussion, it is clear that concepts of interference as well as temporal decay continue to hold an enduring appeal in accounts of forgetting over the short term and the essential role they play in memory consolidation.

1.2.4 Rehearsal and Refreshing

Articulatory rehearsal is a well-established phenomenon. It is assumed that maintenance of verbal information is accomplished by means of vocal or sub-vocal rehearsal (Baddeley and Hitch, 1974). When rehearsal is prevented by articulatory suppression, e.g., by constantly repeating a single word which is unrelated to the memory content, performance is usually reduced. Due to prevention of articulatory or sub-vocal rehearsal, maintenance of memory is disrupted leading to the decay of memory traces (Baddeley et al., 1975). Richardson and Baddeley (1975) studied the effect of articulatory suppression on free recall by presenting lists of 16 words each while asking the participants to also repeat the word 'Hi-ya' during the first or second half of the experiment when word was presented while during the other half of the experiment, they remained silent. They were asked to recall the words after every list in any order. The experiment clearly showed reduction in performance independent of serial position of the word. Even when they changed the modality of presentation of the words (auditory, visual and auditory-visual) in their second experiment, the results were replicated which suggested that although articulatory suppression has a negative impact on recall, it does not lead to full decay of the memory traces and the dipped serial position curve looks similar to the one described by Murdock Jr (1962) but with lower performance levels. Hence, even though other similar studies (Schendel and Palmer, 2007; Ritchie et al., 2015; Romani et al., 2005) have suggested that the effects of articulatory suppression is independent of serial position, it is an important factor that has dominated memory research.

Another concept, distinct from rehearsal was suggested by the TBRS model was discussed briefly earlier (*see section 1.2.2*). They posited that attentional refreshing or the briefly bringing to attention of a just-previously activated thought can also help maintain verbal memory. To demonstrate this, they used a complex span task instead of the simple span task that was used to demonstrate the working memory model (*see section 1.2.2*) proposed by Baddeley and Hitch (1986). Daneman and Carpenter (1980) introduced, first an extended version of the memory span task (they called it reading span) which was one of the first complex span tasks. The difference from the old simple span tasks was that a processing demand was added to a list of to-be-remembered items. In complex span tasks, items are interspersed with distractor items that need to be processed or manipulated. For example, the operation span task combines checking and confirming simple mathematical equations such as "2+6/2 = 5?" with memory for a word or a letter that follows immediately after each equation (Kane et al., 2004). Due to the demand on attention and the constant need for switching attention to different types of stimuli, an attentional 'bottleneck' is invoked and this was central to the TBRS account. Here, short-term forgetting is predicted in the absence of reactivation of the memory trace through attentionally-demanding maintenance processes (attentional refreshing). As previously noted (see section 1.2.2) decay is also a central feature which is countered by attentional refreshing and it is the balance between decay and attentional refreshing that determines forgetting. Additionally, the TBRS model introduces the concept of cognitive load, which is the ratio of the time available to refresh traces against the time attention is taken up by competing distractor processing.

One of the studies that looked at both attentional refreshing and articulatory rehearsal was carried out by Camos et al. (2009) who conducted experiments which measured verbal memory for letters while the participants either had to only solve simple mathematical problems between the presentation of the to-be-remembered stimuli or they had to solve the problems as well as repeat a single word continuously during the presentation of the stimuli. They found that disrupting attentional refreshing had a negative impact on recall but as with articulatory rehearsal, it was independent of serial position and articulatory rehearsal itself. In fact, other studies (Camos et al., 2011; Trapp et al., 2014; Raye et al., 2007) have then gone on to understand that it is two completely different mechanisms within the brain that leads to attentional refreshing and articulatory rehearsal and that both processes are important in the consolidation of memory traces. These concepts of rehearsal and refreshing align perfectly with Thorndike's law of Disuse in that unless regularly used, all memory decays, akin to a muscle that will atrophy if not exercised.

1.2.5 Time based accounts of decay and forgetting

Amongst the time-based models of memory, the temporal distinctiveness models have gained traction in recent times. These models lay more emphasis on the core principle of temporal distinctiveness in memory rather than believing the influence of time to be secondary to this process. Most of the literature in this area has looked into increasing the time given for each stimulus in an attempt to improve temporal distinctiveness and therefore, recall. Note that this is different from the memory consolidation process discussed earlier *(see section 1.2.2)*; however, it may be worth noting that the central concept of temporal distinctiveness allows for better consolidation nevertheless, if the items have increased temporal spacing between them.

The literature in serial processing of information, apart from a few exceptions (Welte and Laughery, 1971; Neath and Crowder, 1996), have presented serial order information for their memory experiments in an equally spaced fashion. The early study by Welte and Laughery (1971) looked at varying presentation schedules for a verbal list of stimuli. These authors were addressing an earlier demonstration that a series of increasing intervals between items in a serial recall situation led to improved recall (Corballis, 1966; Corballis and Loveless, 1967) where they suggested that the outcome was due to cumulative rehearsal, so that greater interval late in the sequence allowed for most rehearsal. But Welte and Laughery argued, and showed, that in a free recall situation, a decreasing schedule permitted participants to quickly write down the last items. In other words, it is a difference at the outcome stage that may account for differences in performance for the different schedules of presentation. In their experiment, participants were shown a set of digits displayed one at a time and there were four conditions - increasing and decreasing inter item interval schedules with free and serial recall conditions. The inter item intervals in the increasing schedule increased in a arithmetic progression, starting with 0.5 sec increased by 0.2 sec up to 1.9 sec and it was exactly the opposite for the decreasing schedule. The results showed that recall for the increasing schedule was better in the later positions for the serial recall condition (when there was greater inter item intervals) but they explained that better performance is due to more opportunity for cumulative rehearsal i.e. when longer inter item intervals occur later in the sequence, participants are able to make more efficient use of time because they have a greater number of items available for rehearsal. However, their results also showed that there was not much difference in recall of the earlier items for all the different conditions. Although the authors attributed his finding to a possible ceiling effect for the earlier items, there could have been other possible explanations such as the predictability of the schedules of presentation after a while, whereby participants spent less effort on the earlier items in a decreasing schedule and this may have masked the true benefits of a decreasing schedule on the earlier items. However, what this study did find was that in the free recall condition, the performance was far better in the decreasing schedule than the increasing schedule, especially in the later items. This finding was significant and the results were attributed to decay and/ or interference at the time but it is important for the present study and needed to be explored further.

Another set of studies investigated the effects of temporal isolation in a serially arranged list by inserting temporal gaps at varying positions and found that performance on the later items was better and the last item may even be transferred to long-term memory when temporal isolation was higher for the last item. Bjork and Whitten (1974) study was one such where they examined temporal distinctiveness by inserting either 12 second interpolated activity (arithmetic problems) before and after each word pair for a list of ten word pairs or no interpolated activity at all. Memory studies have consistently found primacy and recency effects (better recall of first few and last few items) but this study found a larger tendency for the later items to be recalled. They attributed these results to ‘the ratio of the temporal separation of successive to-be-remembered items (or sets of items) to the temporal distance from those items to the point of recall (this later came to be known as the ratio rule) and it is concurrent with Crowder’s (1976) original theory. Taking this a step further, Glenberg and Swanson (1986) combined the temporal distinctiveness theory with the search set theory by providing evidence for how a temporal context can be used to cue recall. They claimed that people create temporally defined search sets and use them when other retrieval strategies may not be easy. Their experiments focused on separating one or more items temporally, thus increasing or decreasing the end of list search set. They found that, under auditory presentation, recall for the last item increased considerably with a longer temporal gap between the last item and the rest of the list.

Following this, studies looked at varying presentation schedules, similar to Welte and Laughery (1971) within a list rather than simply inserting temporal gaps in strategic places in a serial order list as had been done by previous studies. Neath and Crowder (1990) used increasing and decreasing presentation schedules with a view to confirm the so-called ratio rule (Bjork and Whitten, 1974) but were primarily motivated by the fact that there should be an optimal spacing arrangement which could render the serial position function flat. By systematically decreasing a distractor activity (set of digits between presentation of items) from beginning to end of the list and therefore also decreasing the temporal gap, they hypothesized that this would compensate for the recession described in the telephone pole analogy of Crowder. In their experiments, therefore, they produced different schedules by the simple insertion of digits – either 0, 1, 2, 3 or 4 between items to be recalled. The increasing interval condition of a five item list (letters) was created by inserting 0, 1, 2 and 4 digits respectively; a decreasing interval condition which had 4, 2, 1 and 0 digits separating the five items respectively and a constant interval was created by inserting 2 digits between each item. The results did indeed show a higher frequency of recall for the decreasing interval condition as predicted providing evidence for the possibility of an optimal presentation schedule. In a further experiment which used words instead of letters, they tried to manipulate the decreasing interval condition in an attempt to understand the ratio better by having three different decreasing interval conditions for both visual and auditory paradigms. They discovered that conditions with decreasing intervals were not only consistently better for frequency of recall but also the last segment of the serial position curve was rendered relatively flat. Neath and Crowder (1996) further examined serial recall of five-item lists, using increasing and decreasing schedules (in addition to a control regular presentation rate) and fast presentation to minimize rehearsal. An important difference they found in the results was that the increasing schedule showed better performance than the decreasing or constant schedule. They concluded that this could be because of the fact that when it is a short list, regardless of instruction given, participants orient themselves in a forward fashion (report early items first), thus putting them at a disadvantage in the decreasing schedule.

More recent studies such as Brown et al. (2006) have found temporal isolation to be significant for free recall in longer lists of items when rehearsal was prevented using a continuous distractor paradigm. They presented a list of 17 words with increasing or decreasing number of digits for the increasing and decreasing inter item interval conditions respectively and found that the probability of recall of items were higher for the decreasing condition (where the intervals between items increase across the series). Further, in their next experiment, where they used a random inter item interval presentation schedule, they found that the items which had a higher temporal isolation were found to be recalled more frequently. Another study by Lewandowsky et al. (2008) investigated temporal isolation effects in free recall. Their experiment had seven item lists and each list contained six inter item intervals of 50, 100, 200, 400, 800 and 1200ms duration. Instead of having an increasing and decreasing condition, they used all possible permutations of these trials to create 720 unique trials. They found that temporal isolation had an effect on recall if report order was unconstrained and that isolation benefits memory partially due to preferential early report of isolated items. Temporal isolation was also found to benefit recognition (Morin et al., 2010) where nine item lists were presented and a single probe item was presented at the end of each list but the words were presented at a uniform rate (with pre item and post item gaps to ensure temporal isolation) as compared to previous studies.

There have also been many studies with findings contrary to the above studies such as Lewandowsky et al., 2006. Their experiment had seven item lists, and each list contained six inter item intervals of 50, 100, 200, 400, 800 and 1200ms duration. Instead of an increasing and decreasing condition, they used all possible permutations of these trials to create 720 unique trials of intervals which were divided into 6 sets of 120 trials subject such that within each set, each inter-item interval occurred the same number of times (20) at each serial position. They found that a ‘general effect of temporal isolation was absent’ and the frequency of recall items that were temporally crowded was no worse than that of temporally isolated items. Other studies (Geiger and Lewandowsky, 2008; Parmentier et al., 2006) have also found virtually no evidence of temporal isolation benefits in short –term memory when inter item interval is unpredictable and retrieval order has been prescribed. Also, Nimmo and Lewandowsky (2006) varied the isolation of items from 450 ms to 7000 ms and found that it had no effect on serial recall.

1.2.6 Re-examining Forgetting: Beyond Decay

Re-examining the concept of forgetting through the lens of temporal distinctiveness challenges traditional notions that memory loss is primarily due to decay. Instead, forgetting can be understood as a failure to retrieve items that are not temporally distinct from their neighbours. This perspective shifts the focus from the passage of time to the structure of time as it is encoded in memory. Studies such as those by Lewandowsky et al. (2008) and Brown et al. (2006) support this view by showing that memory performance can be enhanced by manipulating the temporal spacing between items, rather than simply reducing the retention interval. Empirical studies have provided substantial support for the temporal distinctiveness approach to forgetting. For example, McKeown and Mercer (2012) demonstrated that memory for complex tones decayed less rapidly when the temporal spacing between items was increased. Similarly, studies using visual stimuli have shown that temporal isolation can improve memory performance, challenging the assumption that forgetting is purely a result of time-based decay (Nieuwenstein & Wyble, 2014; Ricker & Cowan, 2014; Souza & Oberauer, 2014; White & Gresch, 2016). These findings suggest that forgetting can be mitigated by enhancing the distinctiveness of items in memory, providing a new avenue for research. Therefore, the implications of temporal distinctiveness for memory research are profound. By focusing on the relative timing of events, researchers can better understand the conditions under which memory is preserved or lost. This approach also opens up new possibilities for improving memory, such as through the strategic manipulation of temporal spacing in educational settings or memory rehabilitation programs. The shift away from decay-based models represents a significant paradigm change in the field of cognitive psychology.

1.3 Memory for sequences of items

Serial processing of information is an essential ingredient in all human behaviour so also in memory (Lashley, 1951). The introduction of the method of free verbal recall may be traced to Kirkpatrick’s Psychological Review paper of 1894, who noted the better recall by young adults of early and late, relative to mid items in lists of words presented in various ways (Kirkpatrick, 1894). The method, and its close neighbour serial verbal recall, has of course been extremely thoroughly studied and notably has been a bedrock for two-process conceptions of memory. The study of serial processing lends itself very well to further understand temporal spacing and schedules of presentation in memory. However, it is beyond the scope of the present document to discuss the vast empirical evidence available for serial position curves. This section will only attempt to discuss a few studies relevant to the present set of experiments.

1.3.1 Serial Position Curve

Serial position curve is one of the most commonly observed phenomena when using the serial recall experimental paradigm of short-term memory. Although the present work does not interrogate and is not guided by primacy and recency effects, it is important to have an understanding of the vastly studied and regularly observed phenomenon of the serial position curve during recall of a list of items. There are two basic paradigms that have been used to study serially ordered information – free recall and serial recall. In free recall (recall of a list of items in any order), Murdock(1962) first described the 'definite picture of the serial position curve' which explicitly indicated that there was a variation in the frequency of recall of different items in a to-be-remembered list and this variation depended on its position within the list. He found, what he called, primacy effects which is the tendency to remember the first few items in a list and recency effects which refers to the slight increase in the accuracy of recall of the last few or the most recently presented stimuli within a list (see figure 1.1). This phenomenon was later replicated by many studies and not only seen for a verbal list but also for visual-spatial movements, visual-spatial locations, auditory-spatial locations etc. (Avons, 2007; Agam et al., 2010). Serial recall is the recall of a list of items in the same order that it was presented. The serial position effect was seen in this paradigm as well (Jones et al., 1992; Jones and Oberauer, 2013; Baddeley and Hitch, 1974), although admittedly, the bow is not as pronounced, with a slight increase in primacy and a decrease in recency (Page and Norris, 1998).

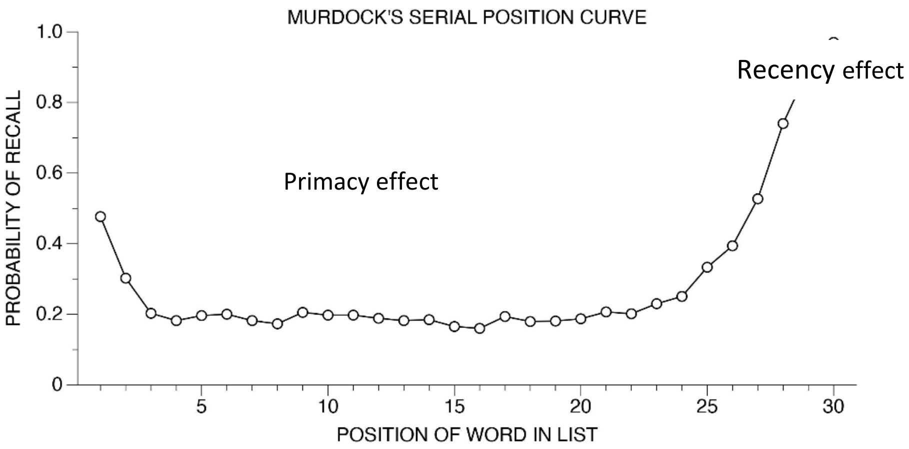

Figure 1.1 The serial position curve as demonstrated by Murdock (1962)

Over the years, researchers have tried to explain this serial position curve using many theoretical accounts. In fact, different theories have been proposed for free and serial recall based on the fact that the recency effect is more pronounced in free recall whereas, for serial recall, the primacy effect is quite significant. Dual- store theories of free recall suggested that the Short Term Store (STS) determined recency and the Long Term Store was concerned with retrieval of not-so-recent items (Atkinson and Shiffrin, 1968; Raaijmakers and Shiffrin, 1981). The SAM model proposed by Raaijmakers and Shiffrin (1981) suggested that items that are presented within the same temporal context become linked together and taking this concept further was Kahana (1996) who proposed the Conditional Response Probability (CRP) function which relates to the probability of recalling a given item to its distance (in the memory list) from the last item recalled. Other similar models called chaining models that attempt to explain memory for serially ordered items (Lewandowsky and Murdock Jr, 1989) and ordinal models (Farrell and Lewandowsky, 2002; Page and Norris, 1998) assume that recall is assisted by the relationships between items or their positions in a sequence. An influential model that explained many of the phenomena associated with serial recall was the phonological loop model of working memory (Baddeley, 1986; Baddeley, 2000; Baddeley and Hitch, 1974) which was discussed earlier (*see section 1.2.2*).

Studies for non-verbal memory of items reveal serial position curves that are slightly different. The recency effect was restricted to the last item and almost no noticeable primacy effect was seen (Broadbent and Broadbent, 1981; Christie and Phillips, 1979; Hines, 1975). Avons (1998) conducted a study wherein, initially he presented participants with lists of novel patterns and asked participants to identify the order in which they were presented. He obtained a markedly U-shaped curve similar to the ones seen in verbal memory. But, after realising that this was probably due to the demand on participants to make a judgement regarding the serial order of the stimuli (which may have involved some element of verbalisation), he conducted another experiment where he asked at random to either report the serial order or simply exposed them to a recognition task at the end of the list. Here, he found that memory for novel visual patterns is independent of serial position and that they did not show the bowed serial position curve observed in verbal memory as well as in his previous experiment. However, another study (Ward et al., 2007) found that it was not really the stimuli itself that contributed towards changes in the serial position curve, but it was the methodology used. The visual and non-verbal serial position curve has not yet been extensively studied like the verbal serial position curve. Therefore, there is potential for exploration within this area.

Temporal clustering or grouping in memory is also another organizational process, and it involves inserting extra pauses into an otherwise regular sequence of items. It is related to "chunking" in that it involves dividing a sequence into smaller sub-sequences, and has large effects on both immediate recall and learning (Winzenz and Bower, 1970). However, temporal grouping enhances memory for unfamiliar sub-sequences, whereas for chunking to occur, the sub-sequences must form familiar patterns. Farrell's model of temporal clustering assumes that people simplify and segment their continuous experience into episodic clusters and items are clustered together in memory as episodes by binding information within an episode to a common temporal context (Farrell, 2012). The present research is more interested in studies exploring temporal spacing within memory for lists of items explained in detail below. A more recent study combined these two seemingly contrasting concepts. A study conducted by Grenfell-Essam, Ward & Mack (2019) found moderate temporal isolation benefits in free and serial recall but they found better advantages for recall when pre-item intervals were longer and post-item intervals were shorter. They argued that this fit with a grouping account in that the longer pre-item interval may encourage participants to divide lists into sub-groups thus making them temporally distinct from other sub-groups with the list.

Another group of models called event-based models envisage that time or the passage of time has an influence on memory in a parallel or secondary manner. They place primary importance on other factors such as output interference (Tulving and Pearlstone, 1966) and primacy gradient Page & Norris (1998). The feature model (Nairne, 1990) has similar views suggesting that memory traces left behind by previous information can overwrite new information thus making it more difficult to remember the new information. The start-end model (Henson, 1998) places more emphasis on the positions of items in a sequence rather than the temporal distance between the items. For example, according to Henson, items are stored in memory as position-sensitive tokens which are then retrieved by reinstating positional codes for each response, and letting tokens compete in parallel for recall.

1.3.2 Exploring temporal spacing within memory for lists

Although there is a growing body of evidence demonstrating that verbal and non-verbal short term memory for lists is determined in part by time between encoding and retrieval (e.g. McKeown et al., 2014; Mercer & McKeown, 2014; Ricker & Cowan, 2010, 2014; Zhang & Luck, 2009), the specific role of the elapsing time is still not very clear (Altman & Schunn, 2012; Mercer, 2014). It may be that time between successive items can help not only encode these items separately but also store them separately (in time) if memory for lists is represented as a psychological time continuum which each item being given enough temporal distance from successive items within memory (Shipstead & Engles, 2013). Two separate time intervals are important for recall, namely, the retention interval between encoding and recognition, and the interval separating each item or inter stimulus interval. As already noted in section 1.2.4, temporal distinctiveness may account for the relationship between these two intervals (Brown et al., 2007; Ecker et al., 2015) which suggests that when the RI is fixed, increasing the temporal isolation of each item in a sequence will increase discriminability by reducing the proactive interference due to previously stored memory items.

In contrast to the decay accounts of forgetting, temporal distinctiveness theories (e.g. Bjork & Whitten, 1974; Brown et al., 2007; Burgess & Hitch, 1999) are interested in the role of relative time (Mercer, 2015) which suggests whether any given item is remembered, is dependent on its relative temporal distance from other items before or after it has been presented (Brown & Lewandowsky, 2010). But it is important to evaluate this within the context of the psychological timeline of memory as well since as time passes, each item will become logarithmically compressed (Grange & Cross, 2015), such that the distinctiveness of each item is reduced as they recede into the past (Lewandowsky, Brown, Wright, & Nimmo, 2006). As mentioned earlier, recall is controlled by both RI and the temporal isolation of each item relative to its neighbours (Cowan, Saults, & Nugent, 1997; Unsworth, Heitz, & Parks, 2008). Recent interpretation of temporal distinctiveness, namely the SIMPLE model (Brown et al., 2007) has explained this relationship as the ratio rule (e.g. Glenberg, Bradley, Kraus, & Renzalia, 1983) which means that recall is determined by the ratio between the inter-stimulus interval between each item and the retention interval between initial encoding and retrieval (Ecker, Tay et al., 2015; Oberauer & Lewandowsky, 2008; Souza & Oberauer, 2014). As this ratio increases, items become less distinct from each other, and this results in poorer performance during recognition or recall.

There is also evidence supporting temporal distinctiveness models in visual memory performance (e.g. Guérard, Neath, Surprenant, & Tremblay, 2010; Shipstead & Engles, 2013; Souza & Oberauer, 2015). In a study of visual list memory, Shipstead and Engles (2013) found that participants had difficulty detecting changes to a visual list seen previously (four coloured squares) when the retention intervals where longer, and especially so, when there was only a short inter-trial interval between the current list and the previous list. These findings were further studied by Souza and Oberauer (2014) who varied the distinctiveness of memory items by manipulating the ratio between the retention interval and the inter-trial interval (ITI). They utilised a colour recall task, where the participants were exposed to a list of six coloured circles before having a short (1000ms) or long (3000ms) retention interval. After each trial there was either a short ITI (1000ms) or long ITI (7500ms). They found that performance was best for a relatively short retention interval and a long inter-trial interval, which meant that each list became temporally distinct from each other.

It may be helpful to explore the SIMPLE model in some detail for the purposes of this thesis. This model is based on the idea that memory retrieval is influenced by the distinctiveness of items in memory relative to their temporal and contextual neighbours. The SIMPLE model has been widely applied to various memory phenomena, including serial recall, free recall, and recognition tasks, providing a unified framework that does not rely on traditional decay theories. However, its application and effectiveness, particularly in explaining reduced recency effects in certain memory tasks, has been a subject of debate. One of the primary strengths of the SIMPLE model is its reliance on temporal distinctiveness as a core explanatory mechanism. Unlike traditional decay models, which suggest that memory traces fade over time, the SIMPLE model argues that forgetting occurs because items become less distinct as they recede into the past or as more items are encoded. This perspective aligns with evidence showing that memory performance can be influenced by manipulating the temporal spacing of items, rather than merely the passage of time. For example, studies have demonstrated that increasing the temporal gap between items improves recall, supporting the idea that temporal distinctiveness enhances memory retrieval (Brown et al., 2006; Lewandowsky et al., 2008). The SIMPLE model's ability to account for different memory tasks is another notable strength. It provides a coherent explanation for both serial and free recall tasks, which often exhibit different patterns of memory performance. In serial recall, where items must be recalled in the order presented, the model explains the reduced recency effect as a result of the constrained retrieval process. The items at the end of the list are less temporally distinct from their predecessors, leading to weaker recency effects. In contrast, free recall allows for the retrieval of the most recent items first, which are more temporally distinct, thereby enhancing the recency effect. This flexibility in accounting for different tasks demonstrates the model's robustness. The SIMPLE model has also been applied successfully to non-verbal and complex memory tasks, which often involve stimuli that are not easily verbalizable or that have complex structures. For instance, the model has been used to explain memory performance for spatial locations, visual patterns, and even abstract shapes, where traditional verbal rehearsal mechanisms do not apply (Guérard et al., 2010; Mercer, 2014). This adaptability makes the SIMPLE model a powerful tool for understanding a wide range of memory phenomena, beyond those typically explained by verbal-based memory models. Although the model also has limitations including over-reliance on logarithmic transformations and simplifying the complexities of memory recall as well as some challenges in explaining long term memory processes and reduced recency effects or chunking effects, this model is considered to be a potentially useful resource for the present series of experiments and has been used to model data obtained.

Despite its limitations, the SIMPLE model can be seen as complementary to dual-store models of memory, such as the Atkinson and Shiffrin (1968) model, which posits separate stores for short-term and long-term memory. The SIMPLE model's focus on temporal distinctiveness aligns with the idea that items in short-term memory are more vulnerable to interference, which can be mitigated by enhancing temporal isolation. By integrating the SIMPLE model's insights into temporal distinctiveness with the dual-store framework, researchers can develop a more nuanced understanding of how items transition from short-term to long-term memory, and how distinctiveness can play a role in this process. Similarly, the SIMPLE model's emphasis on temporal distinctiveness also opens the door for integration with event-based models of memory, which focus on the importance of specific events or contexts in shaping memory retrieval. Event-based models suggest that memory is organized around significant events or episodes, which serve as retrieval cues (Tulving, 1983). The SIMPLE model's concept of temporal isolation can be extended to consider how events that are temporally distinct may serve as stronger retrieval cues, thereby enhancing memory performance. This integration could provide a more comprehensive framework for understanding how both temporal and contextual factors influence memory retrieval.

Therefore, temporal distinctiveness enables the understanding of a forgetting function based on the ratio of two time intervals. However, there is evidence and data inconsistent with this ratio rule (Ricker & Cowan, 2014; Ricker et al., 2014; Mercer, 2015; McKeown et al., 2014). The temporal distinctiveness account was tested in visual memory using a 'recent probe' task (McKeown et al., 2014; Mercer & Duffy, 2014). In McKeown et al. (2014) participants were shown visual stimuli (two abstract shapes). Following a retention interval (RI), a probe item (either a positive probe, a negative probe or a recent negative probe - an item that had occurred within a target list on a prior trial) was presented which participants were asked to identify as either having seen before or not. The recent negative probes task was important to the study and helped them understand the strength of a memory trace from earlier trials while the participants could not have been engaging in any active maintenance mechanisms. This recent negative probe led to proactive interference, and it took participants longer to respond to the recent negative probe than the simply negative probe (Berman et al., 2009). Across two experiments, McKeown et al., reported slowed recent negative responses even where there were high inter trial intervals – more than 6 s. Therefore, these authors argued that their data did not conform to the usual ratio rule of temporal distinctiveness account – the memory trace effect was not influenced by the ratio of inter-trial interval to retention interval on the current trial.

When it comes to non-verbal memoranda, as previously noted, there are very few studies exploring temporal spacing within memory for lists of non-verbal or visual items. However, there are some studies that investigated this phenomenon of temporal isolation and distinctiveness effects in non-verbal memory. The most recent study that indicates the role of temporal distinctiveness in non-verbal memory is that of Souza and Oberauer (2015). Their study challenged the idea that time-based forgetting in visual memory is a result of decay and their results showed that the relative spacing of events in time determines how much interference is seen and hence, performance. Guérard et al. (2010) also studied distinctiveness in spatial memory by asking participants to recall the order in which a series of spatially located dots were presented on a computer screen. They also varied the temporal distinctiveness by varying the inter-item intervals (0 s - 4 s). Their results revealed that temporal distinctiveness usually seen in verbal sequences is also seen in serially presented spatial information. Mercer (2014) also investigated whether temporal distinctiveness had an important role to play in visual short-term memory. He presented participants with novel visual patterns called Fribbles and created four different experimental conditions by varying the Retention Intervals and Inter-Trial Intervals (eg. RT: ITI = 2:1, 2:4, 6:3 and 6:12). He found that a longer ITI had an advantageous effect, which in turn supported temporal distinctiveness theories in that temporally well-spaced out stimuli are more distinctive and are better remembered.

Taking all of this literature into consideration, although there is plenty of evidence for the temporal distinctiveness accounts, the validity of these accounts may be questioned within a variety of contexts. The conventional temporal distinctiveness accounts relied on a ratio rule, namely the relative intervals – the inter-trial interval relative to the current trial retention interval – and there are many situations where that rule cannot be applied in a straightforward manner. For example, memory compression – a mental variable determined by time since encoding and number of items encoded as illustrated by Crowder (1976). Psychological time, unlike physical time, is compressive and events in the past become less distinct from each other and more difficult to recall. This phenomenon was explained lucidly in a theory originally put forward by Crowder (1976) and is known as his telephone pole analogy of psychological time (see Figure 1.2). He explains -

The items in a memory list, being presented at a constant rate, pass by with the same regularity as do telephone poles when one is on a moving train. The crucial assumption is that just as each telephone pole in the receding distance becomes less and less distinctive from its neighbours, likewise each item in the memory list becomes less distinctive from the other list items as the presentation episode recedes into the past. Therefore, retrieval probability is being assumed to depend on discriminability of traces from each other. (Crowder, 1976: 462)

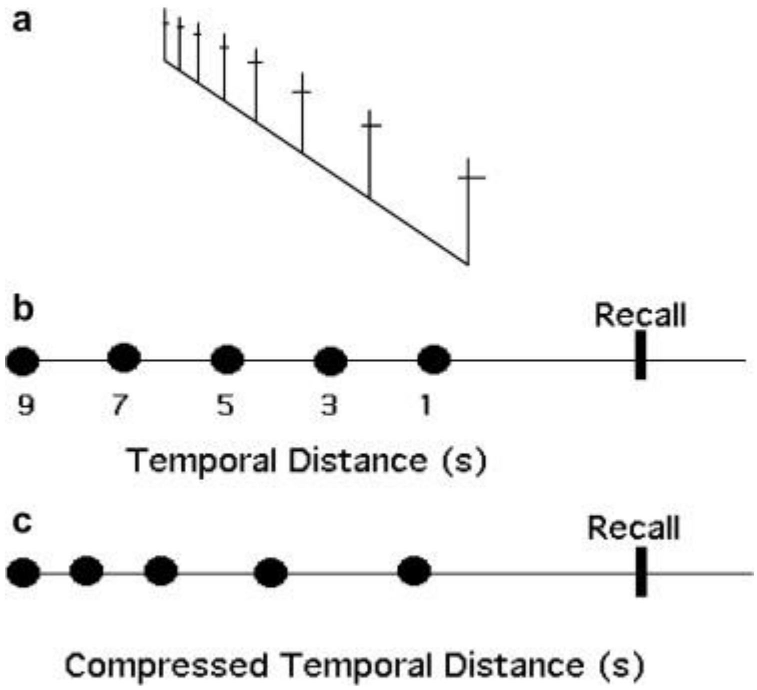

Figure 1.2 An illustration of the telephone pole analogy of memory taken from Brown et al, 2009

Therefore, accounts of temporal distinctiveness cannot be readily applied to all situations and may be just one factor governing forgetting in the short term.

1.4 Summary and rationale for the present set of experiments.

Temporal isolation and distinctiveness have enjoyed a recent resurgence in interest; however, we are proposing a new concept of temporal distortion of memory with its feet firmly set within the temporal distinctiveness models.

The present series of experiments serves to answer three questions – (a) whether in fact there is evidence for temporal isolation benefitting memory, (b) would the application of an optimal spacing schedule for a serially ordered list maximise recall and render the serial position curve flat and if so, (c) what is that optimal spacing schedule to reverse the distortion in memory. Revisiting Figure 1.2, when stimuli is presented in a serial order, according to Crowder, the temporal record of memory is compressed (see a & b of Figure 1.3). However, the present study is an attempt to reverse that compression so that the temporal record is no longer compressed by applying negative compression (see c of Figure 1.3)

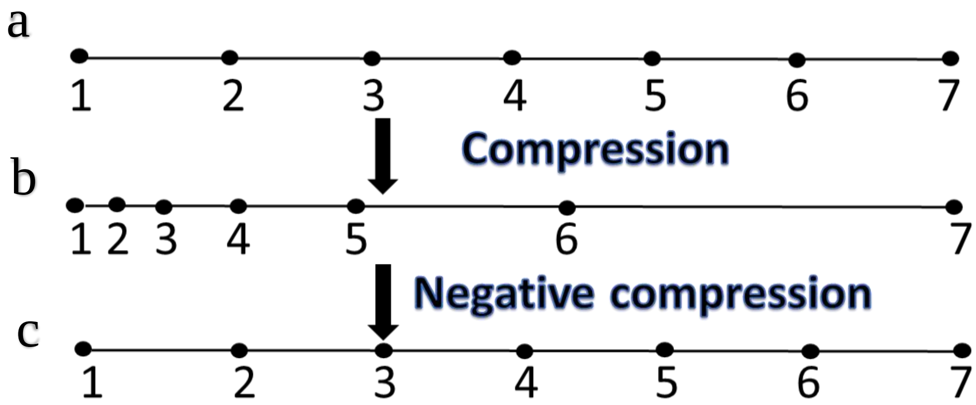

Figure 1.3 An illustration of the attempt to reverse the compression in the temporal record of memory.

As explained in *section 1.2.5,* only a very limited number of studies (Welte and Laughery, 1971; Neath and Crowder, 1990; Neath and Crowder, 1996) have studied progression of the time schedules in an approximate sense, be it arithmetic or geometric. An educated guess based on the ratio rule initially proposed by Bjork and Whitten (1974) and further explained by Neath and Crowder (1990), Glenberg and Swanson (1986), Neath and Crowder (1996) led to the logarithmic function of memory. This rule is based on the very well-known principle of Just Noticeable Differences in Weber's Law. The law states that the relationship between stimulus and perception is logarithmic. The ratio rule – and indeed the two-process conception of working and long-term memory – has guided the early work already outlined above. In the opening paragraph, a reference was made to the notion of a 'distortion' in the representation of the immediate past, and the proposal that schedules of presentation of items to be recalled might be arranged to reverse or at least dilute that distortion. One may think, as an illustration, of a gentle high-pass filter characteristic that exactly reverses or compensates for a gentle one low-pass earlier in a stream of auditory information. Here, the distortion is viewed as temporal – and the 'contracting' presentation order of items to be recalled as reversing the inherent compressive function of immediate memory. Therefore, it would be safe to hypothesize that psychological time in memory is logarithmic as well. To prove this, the present set of experiments have been designed where the stimuli are not equally but logarithmically spaced to correct the temporal distortion in memory.

This paper therefore proposes a new conception of serial recall using logarithmic physical time or negative compression to reverse the effects of compressed psychological time. Presentation of information in logarithmically spaced intervals will (a) confirm principles of temporal distinctiveness and (b) lead to better recall of items presented (c) render serial position curve flat and reverse the distortion in memory. The first aim is to investigate the effects of spacing of verbal stimuli in Immediate Free Recall and Immediate Serial Recall as previous studies have used these paradigms extensively and it is easy to manipulate the presentation schedules.

Chapter 2 - The question of temporal schedules and verbal memoranda

2.1 Introduction to Experiment 1

This first study in the present series sets out to explore the effects of varying temporal intervals between stimuli on their subsequent recall. The reader may recall that in Chapter 1, reference was made to the notion of a 'distortion' or 'compression' in the representation of the immediate past, and the proposal that schedules of presentation of items to be recalled might be arranged to reverse or at least partially address that distortion. Here, the distortion is viewed as temporal – and the 'contracting' or progressively 'decreasing' presentation order of memoranda may be seen as reversing the inherent compressive function of immediate memory. Therefore, it may be safe to hypothesize that psychological time in memory is compressive in an approximately logarithmic fashion. To address this, the present experiment was designed where the stimuli are not equally, but logarithmically sequenced. As a starting point in Experiment 1, considering that the logarithmic function appears fundamental within perceptual systems (witness the frequency selectivity of the peripheral auditory system), the compressive characteristic of the memory distortion was assumed to be a simple power to base 2 logarithmic series of temporal intervals. Verbal stimuli were used here which permit for a number of advantages. Firstly, verbal memoranda may be administered easily and more importantly perhaps, the recall response is straightforward (whereas this may not be the case for more abstract non-verbal memoranda). Additionally, various aspects of verbal stimuli, such as word frequency, length, concreteness, and abstractness can be controlled. This control allows for more precise manipulation of variables and better interpretation of how these factors influence memory. The study of verbal memory also has a rich theoretical foundation and has direct relevance to the study of language-based cognitive processes such as encoding, retrieval and rehearsal which can be explored in some detail when analysing the results. The availability of several well-established research resources to study verbal memory, such as the Toronto word pool, with known psycholinguistic properties makes it a more attractive and practical stimulus group for experiments. Verbal memory tasks closely resemble real-world memory tasks, such as remembering lists, instructions, or narratives. Understanding verbal memory processes has practical implications for improving learning and memory in everyday life, such as enhancing study techniques, developing memory aids, or treating memory impairments.

The first aim was to examine temporal schedules within Immediate Free Recall and Immediate Serial Recall as previous studies have used these paradigms extensively and it is relatively easy to manipulate the presentation schedules. The effects of manipulating the inter-stimulus intervals in a serially ordered word list consisting of 9 words was examined. Three different item-lag or inter stimulus interval conditions (ISI conditions) were arranged: increasing ISI, decreasing ISI and fixed irregular ISI, where the 'starting' point on the schedule was the first presented item. These schedules were chosen based on the fact that the decreasing ISI schedule was of primary interest, the increasing ISI schedule would serve as a control condition and the fixed irregular ISI schedule would reduce the predictability of the previous ISI schedules (this notion of predictability will be addressed in Discussion). On each trial, participants were shown 9 words for 1 second each with varying ISI. After each trial, they were asked to recall the words either in the same order that they observed them (serial recall) or in any order (free recall). One may note that, while examining the results, items 1 and 9 were omitted from each schedule. Here it is admitted that a critical factor that was omitted from consideration while designing the experiment was that items 1 and 9 do not follow the respective temporal interval schedules and an appropriate temporal spacing calculation could not be made for these items; for example, there is no straightforward ‘temporal isolation’ calculation possible for these items, since such a calculation takes account of preceding and following ISIs. An attempt is made to correct this design flaw in the following experiments; in the present reporting of data these recall of these items is considered separately.

One key prediction, arising out of consideration of contemporary accounts of temporal isolation detailed in Chapter 1, is that presentation of information in logarithmically spaced intervals will lead to enhanced recall for the items with larger inter-stimulus intervals; a second and more novel expectation is that the decreasing ISI schedule will reverse the afore-mentioned distortion in immediate memory for the past which will in turn lead to better recall in this schedule; and a third prediction is that by reversing the distortion in memory for items in the immediate past, the decreasing ISI schedule will lead to (approximately) equal probability of recall for all the items in the list and therefore, will render the serial position curve flat. Again, the key interest is in the deceasing ISI schedule of presentation.

2.2 Methodology

2.2.1 Participants.

Thirty volunteers (29 females and 1 male) with an average age of 18.3 years from the University of Leeds Participant pool were native English speakers, had normal/corrected to normal vision and had not been diagnosed with a neurological problem were included.

2.2.2 Stimuli.

The stimuli consisted of 486 words taken from the Toronto Word Pool (Friendly et al., 1982) and divided into 6 experimental blocks.

2.2.3 Materials and Design.

The experiment was designed on E-prime software which assured the accuracy of timing and the words were presented on a computer screen. All stimuli were presented on the centre of the screen, in a 60- point Arial font for 1000ms. They were then given a response sheet to record their responses. Each of the 6 experimental blocks consisted of 9 sets of 9 words each. The inter-stimulus interval (ISI) between individual words was manipulated to create two item-lag conditions as shown in Fig. 2.1 - increasing ISI with 50, 100, 200, 400, 800, 1600, 3200 and 6400ms ISIs from Word 1 to 9; decreasing ISI with 6400, 3200, 1600, 800, 400, 200, 100 and 50ms ISIs from Word 1 to 9; and an additional item lag condition was also created, not shown in the figure, which was the fixed irregular ISI with 50, 800, 200, 6400, 100, 1600, 400 and 3200ms ISIs from Word 1 to 9. A within-subjects design was used, with all participants exposed to the three ISI conditions in counterbalanced order.

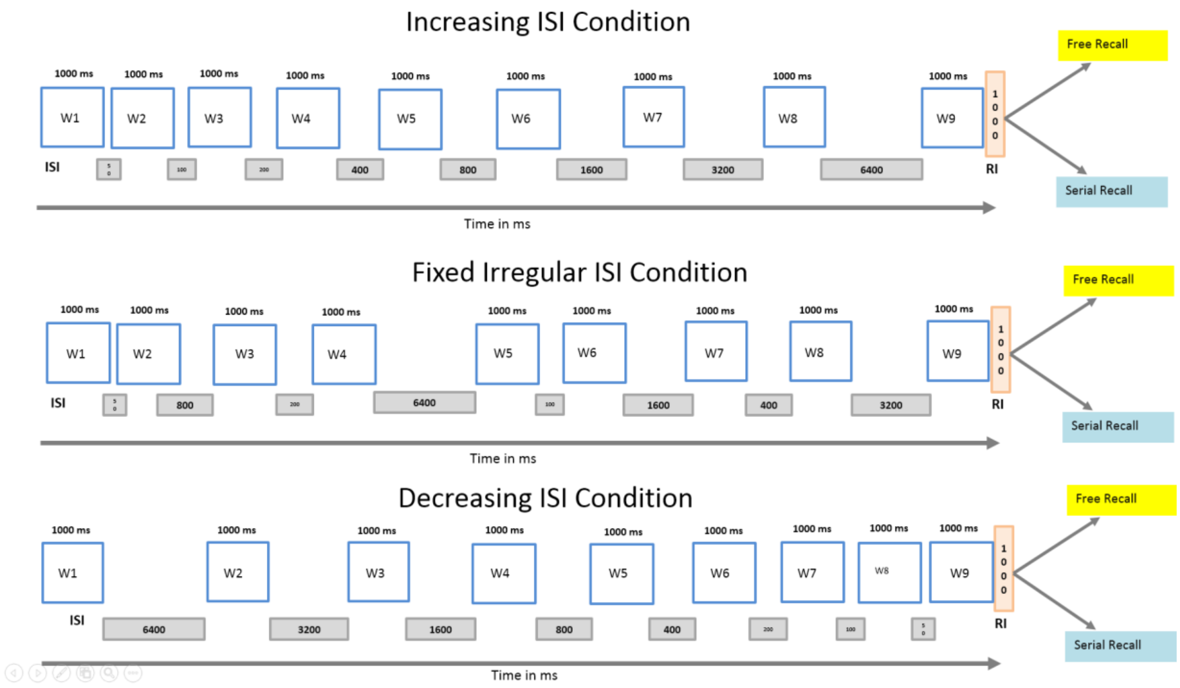

Figure 2.1 Inter Stimulus Intervals (ISI) in the three the item lag conditions (Increasing ISI, Fixed Irregular ISI and Decreasing ISI)

2.2.4 Procedure.

Participants completed a simple computer administered verbal recall task consisting of six experimental blocks. Each block had 9 sets of 9 words each with alternating increasing, decreasing and fixed irregular ISI schedules. As shown in Fig. 2.2, participants completed 6 experimental blocks which meant there were 18 trials per item lag conditions. They were instructed to carefully observe words that were shown on the screen and were informed that they will be asked to recall them at the end of each set when they were shown the picture of a pen on screen. They were provided with a response sheet with a table showing Trial Number in the columns and the Serial Positions 1-9 in the rows. In the free recall condition, the participants could write down in any row that they wished but in the serial recall condition, they could only write their responses in serial order starting from serial position 1 to serial position 9. However, they were given free choice even in the serial recall condition as to the temporal order in which they wrote down the items as long as they attempted to write the item down in the corresponding serial position row. For instance, participants were required to write the first list item in the first row, the second list item in the second row and so on, such that the last item of the list was written in the last row of the response table. This, in turn, also meant that participants were able to know that the list length was 9 items on each trial and they were also aware that there were several trials. Therefore, the serial recall condition employed in this experiment is the free choice serial recall, where participants were allowed to recall the words in any temporal order so long as they attempted to recall the serial order as well. Additionally, the scoring was also done in a free recall manner in which an item is scored as correct if it was recalled whether the serial position was correctly recalled or not. Participants were tested individually with the experimenter present in the room they were obeying the instructions.

They were given as much time as required to write down the words they recalled on the response sheet provided. Each experimental block was separated by a break (minimum length of 3 minutes). Half the experimental blocks (first three blocks) were recorded as free recall and the other half (last three blocks) as serial recall. Therefore, the free recall tasks were completed first. The experimental session lasted no longer than 55 minutes (including breaks).

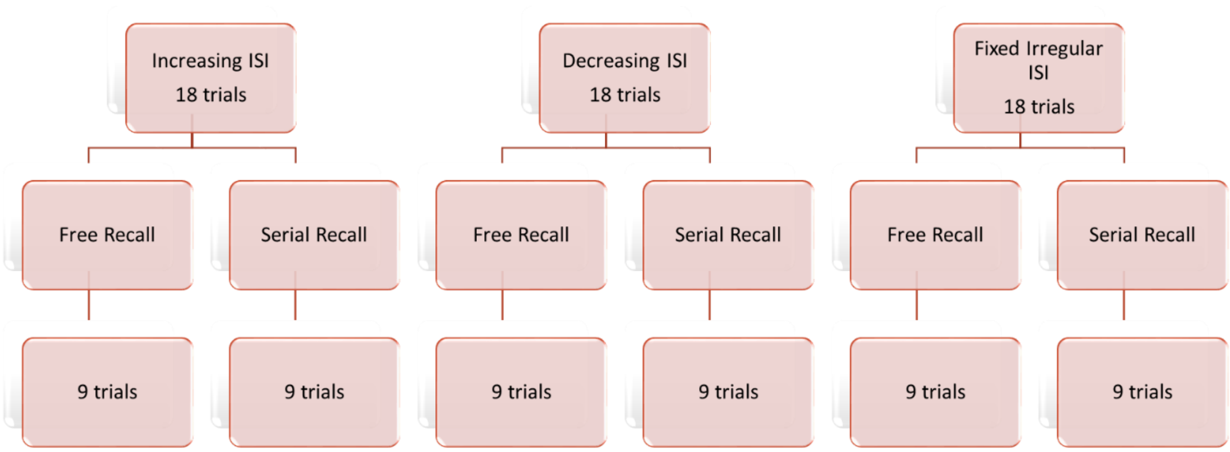

Figure 2.2 Number of trials with serial and free recall in the different item lag conditions (Increasing ISI, Decreasing ISI and Fixed Irregular ISI).

2.3 Results

2.3.1 Psycholinguistic properties of the verbal stimuli

The psycholinguistic properties of the words used in three different ISI conditions (increasing, decreasing and irregular ISI) were analysed to ensure comparability across conditions. A total of 486 words were used across three conditions (162 words each) and they were analysed for the variables of Imagery, Concreteness, and Word Frequency as the word length was the same across all the words used in the study (two syllables long). The Shapiro-Wilk test was used to assess the normality of the distributions for each condition within each variable. For Imagery, the results indicated significant deviations from normality in all three conditions: Increasing ISI condition, $W(162) = 0.954$, $p < 0.001$; Decreasing ISI condition, $W(162) = 0.964$, $p < 0.001$; and Irregular ISI condition, $W(161) = 0.966$, $p < 0.001$. Similarly, for Concreteness, the Shapiro-Wilk test showed significant deviations from normality in all three conditions: Increasing ISI condition, $W(162) = 0.914$, $p < 0.001$; Decreasing ISI condition, $W(162) = 0.931$, $p < 0.001$; and Irregular ISI condition, $W(161) = 0.913$, $p < 0.001$. For Word Frequency, the Shapiro-Wilk test also indicated significant deviations from normality across all conditions: Increasing ISI condition, $W(162) = 0.413$, $p < 0.001$; Decreasing ISI condition, $W(162) = 0.623$, $p < 0.001$; and Irregular ISI condition, $W(161) =$

0.524, p <0.001. These results suggest that the distributions for Imagery, Concreteness, and Word Frequency were not normally distributed across the three conditions.

Given that all variables significantly deviated from normality, non-parametric tests were conducted. A Friedman test was conducted to examine whether there were significant differences in Imagery, Concreteness, and Word Frequency across the three conditions. The test revealed a statistically significant difference for Imagery across the three conditions, $\chi^2(2) = 518.084$, $p < 0.001$. However, no significant differences were found for Concreteness, $\chi^2(2) = 1.777$, $p = 0.411$, or Word Frequency, $\chi^2(2) = 1.406$, $p = 0.495$.

Following the significant Friedman test for Imagery, post hoc comparisons using the Wilcoxon signed-rank tests were performed to identify specific differences between conditions. However, none of the pairwise comparisons for Imagery were statistically significant after applying the Bonferroni correction. The comparisons between Increasing ISI condition and Decreasing ISI condition ($Z = -1.52$, $p = 0.129$), Decreasing ISI condition and Irregular ISI condition ($Z = -0.94$, $p = 0.348$), and Increasing ISI condition and Irregular ISI condition ($Z = -0.71$, $p = 0.480$) all failed to reach significance.

Similarly, Wilcoxon signed-rank tests conducted for Concreteness and Word Frequency revealed no significant differences between any of the conditions. For Concreteness, the comparisons between Increasing ISI condition and Decreasing ISI condition ($Z = -0.45$, $p = 0.652$), Decreasing ISI condition and Irregular ISI condition ($Z = -0.97$, $p = 0.331$), and Increasing ISI condition and Irregular ISI condition ($Z = -0.86$, $p = 0.390$) were not significant. For Word Frequency, the comparisons between Increasing ISI condition and Decreasing ISI condition ($Z = -1.05$, $p = 0.292$), Decreasing ISI condition and Irregular ISI condition ($Z = -0.50$, $p = 0.615$), and Increasing ISI condition and Irregular ISI condition ($Z = -0.06$, $p = 0.951$) were also not significant. Therefore, it can be concluded that there were no significant differences in Imagery, Concreteness, and Word Frequency across the three ISI conditions.

The data were analysed for differences in imagery, concreteness, and word frequency across two conditions, free recall ($N = 235$) and serial recall ($N = 243$). The mean score for imagery in free recall was 4.47 ($SD = 1.48$), and in serial recall, it was 3.69 ($SD = 1.27$). For concreteness, the mean in free recall was 4.64 ($SD = 1.53$), and in serial recall, it was 3.76 ($SD = 1.08$). Word frequency had a mean of 61.83 ($SD = 97.69$) in free recall, and 78.87 ($SD = 175.79$) in serial recall.

Tests of normality using the Shapiro-Wilk test indicated that the data significantly deviated from a normal distribution for all variables across both conditions. Specifically, the imagery scores significantly deviated from normality in both the free recall condition, $W(242) = 0.947$, $p < 0.001$, and the serial recall condition, $W(243) = 0.971$, $p < 0.001$. The concreteness scores also significantly deviated from normality in both the free recall condition, $W(242) = 0.916$, $p < 0.001$, and the serial recall condition, $W(243) = 0.922$, $p < 0.001$. Similarly, significant deviations from normality for word frequency scores were also seen in both the free recall condition, $W(242) = 0.580$, $p < 0.001$, and the serial recall condition, $W(243) = 0.411$, $p < 0.001$.

Given that all variables significantly deviated from normality, non-parametric tests (Friedman test and subsequent post hoc tests) were conducted as was done previously. The results of the Freidman test indicated that there was a statistically significant difference in these psycholinguistic properties across the conditions, $\chi^2(5, N = 242) = 583.444$, $p < 0.001$.

Post-hoc analysis using the Wilcoxon signed-rank tests was conducted to examine the pairwise differences between the free recall (FR) and serial recall (SR) conditions for each psycholinguistic property. The Wilcoxon signed-rank test indicated that imagery scores were significantly higher in the free recall condition ($M = 4.51$, $SD = 1.48$) than in the serial recall condition ($M = 3.69$, $SD = 1.27$), $Z = -6.18$, $p < 0.001$. Similarly, concreteness scores were significantly higher in the free recall condition ($M = 4.67$, $SD = 1.52$) compared to the serial recall condition ($M = 3.76$, $SD = 1.08$), $Z = -6.73$, $p < 0.001$. However, there was no significant difference in word frequency between the free recall ($M = 61.99$, $SD = 97.38$) and serial recall conditions ($M = 78.87$, $SD = 175.79$), $Z = -0.29$, $p = 0.772$.

Furthermore, the psycholinguistic properties of the words used across six different recall conditions (Increasing, Decreasing, and Irregular ISI free recall as well as Increasing, Decreasing, and Irregular ISI serial recall) were analysed to ensure comparability across conditions. The words were analysed for the variables of Imagery, Concreteness, and Word Frequency. The Shapiro–Wilk test was used to assess the normality of the distributions for each condition within each variable. For Imagery, the results indicated significant deviations from normality in most conditions: Increasing ISI free recall, $W(81) = 0.933$, $p < .001$; Decreasing ISI free recall, $W(81) = 0.940$, $p < .001$; Irregular ISI free recall, $W(81) = 0.949$, $p = .003$; and Increasing ISI serial recall, $W(81) = 0.958$, $p = .009$. Decreasing ISI serial recall, $W(81) = 0.971$, $p = .062$, and Irregular ISI serial recall, $W(81) = 0.973$, $p = .082$, did not show significant deviations, suggesting approximate normality for these two conditions. Similarly, for Concreteness, the Shapiro–Wilk test showed significant deviations from normality across all six conditions: Increasing ISI free recall, $W(81) = 0.909$, $p < .001$; Decreasing ISI free recall, $W(81) = 0.921$, $p < .001$; Irregular ISI free recall, $W(81) = 0.906$, $p < .001$; Increasing ISI serial recall, $W(81) = 0.904$, $p < .001$; Decreasing ISI serial recall, $W(81) = 0.940$, $p < .001$; and Irregular ISI serial recall, $W(81) = 0.915$, $p < .001$. For Word Frequency, the Shapiro–Wilk test also indicated significant deviations from normality across all conditions: Increasing ISI free recall, $W(81) = 0.537$, $p < .001$; Decreasing ISI free recall, $W(81) = 0.619$, $p < .001$; Irregular ISI free recall, $W(81) = 0.604$, $p < .001$; Increasing ISI serial recall, $W(81) = 0.432$, $p < .001$; Decreasing ISI serial recall, $W(81) = 0.621$, $p < .001$; and Irregular ISI serial recall, $W(81) = 0.457$, $p < .001$. These results suggest that the distributions for Imagery, Concreteness, and Word Frequency were not normally distributed across the six recall conditions.

Given that all variables significantly deviated from normality, non-parametric tests were conducted. Separate Friedman tests were performed to examine differences across the six conditions for Imagery, Concreteness, and Word Frequency. For Imagery, the Friedman test revealed a statistically significant difference across the six conditions, $\chi^2(5) = 35.734$, $p < .001$. Similarly, for Concreteness, a statistically significant difference was also found, $\chi^2(5) = 40.443$, $p < .001$. However, for Word Frequency, the Friedman test indicated no significant difference across conditions, $\chi^2(5) = 7.141$, $p = .210$. These results suggest that the distributions of Imagery and Concreteness scores significantly differed across conditions, whereas Word Frequency remained comparable.

Wilcoxon Signed Ranks Tests were conducted to compare Imagery scores between the six conditions. Results indicated that imagery scores for the Increasing ISI serial recall condition were significantly lower than the scores for the Increasing ISI free recall condition, $Z = -4.638$, $p < .001$. Similarly, the imagery scores for the Decreasing ISI serial recall condition were significantly lower than the scores for the Decreasing ISI free recall condition, $Z = -4.288$, $p < .001$, and the imagery scores for the Irregular ISI serial recall condition were significantly lower than the scores for the Irregular ISI free recall condition, $Z = -3.028$, $p = .002$.

However, no significant differences were found between imagery scores for Decreasing ISI and Increasing ISI free recall, $Z = -0.620$, $p = .535$, or between Irregular ISI free recall and Increasing ISI free recall, $Z = -0.813$, $p = .416$. Comparisons between imagery scores for Decreasing ISI and Increasing ISI serial recall, $Z = -1.504$, $p = .133$, and between the imagery scores for Irregular ISI free and serial recall, $Z = -0.171$, $p = .864$, also revealed no significant differences. Results also showed no significant differences between the Decreasing ISI free recall and Irregular ISI free recall conditions, $Z = -0.335$, $p = .738$, and no significant differences between the Decreasing ISI serial recall and Irregular ISI serial recall conditions, $Z = -1.849$, $p = .064$. These findings suggest that some comparisons, particularly those involving Increasing, Decreasing, and Irregular ISI serial recall conditions relative to their matched Increasing, Decreasing, and Irregular ISI free recall conditions, showed significant reductions in imagery ratings, while others did not differ significantly. This has already been demonstrated by the results obtained when comparing the psycholinguistic properties between the free and serial recall conditions.

Wilcoxon Signed Ranks Tests were also conducted to compare Concreteness scores between the six conditions. Results indicated that Concreteness scores for the Increasing ISI serial recall condition were significantly lower than the scores for the Increasing ISI free recall condition, $Z = -3.910$, $p < .001$. Similarly, the Concreteness scores for the Decreasing ISI serial recall condition were significantly lower than the scores for the Decreasing ISI free recall condition, $Z = -5.025$, $p < .001$, and the Concreteness scores for the Irregular ISI serial recall condition were significantly lower than the scores for the Irregular ISI free recall condition, $Z = -2.922$, $p = .003$.

However, no significant differences were found between Concreteness scores for Decreasing ISI and Increasing ISI free recall, $Z = -0.062$, $p = .950$, or between Irregular ISI free recall and Increasing ISI free recall, $Z = -1.196$, $p = .232$. Comparisons between Concreteness scores for Decreasing ISI and Increasing ISI serial recall, $Z = -1.400$, $p = .162$, and between the Concreteness scores for Irregular ISI free and serial recall, $Z = -0.002$, $p = .998$, also revealed no significant differences. Results also showed no significant differences between the Decreasing ISI free recall and Irregular ISI free recall conditions, $Z = -1.386$, $p = .166$, and no significant differences between the Decreasing ISI serial recall and Irregular ISI serial recall conditions, $Z = -1.214$, $p = .225$. These findings suggest that, like for Imagery, significant reductions in Concreteness ratings were found for the serial recall conditions relative to their matched free recall conditions, while other comparisons did not differ significantly. We already know this from the results obtained when comparing the psycholinguistic properties between the free and serial recall conditions.

Wilcoxon Signed Ranks Tests were additionally conducted to compare Word Frequency scores between the six conditions. Results indicated that no significant differences were found between the Increasing ISI serial recall and Increasing ISI free recall conditions, $Z = -1.881$, $p = .060$. Similarly, no significant differences were found between Decreasing ISI serial recall and Decreasing ISI free recall, $Z = -0.244$, $p = .807$, or between Irregular ISI serial recall and Irregular ISI free recall, $Z = -1.723$, $p = .085$.

Additionally, comparisons between Decreasing ISI and Increasing ISI free recall, $Z = -1.156$, $p = .248$, between Irregular ISI free recall and Increasing ISI free recall, $Z = -1.718$, $p = .086$, and between Decreasing ISI and Increasing ISI serial recall, $Z = -1.105$, $p = .269$, also showed no significant differences. Furthermore, comparisons between Irregular ISI free and serial recall, $Z = -1.410$, $p = .158$, did not reveal significant differences. No significant differences were seen between Decreasing ISI free recall and Irregular ISI free recall conditions, $Z = -1.718$, $p = .086$, and no significant differences between Decreasing ISI serial recall and Irregular ISI serial recall conditions, $Z = -0.127$, $p = .899$. These findings suggest that, unlike Imagery and Concreteness, Word Frequency scores remained comparable across the six recall conditions.

Analysis was also completed of the psycholinguistic properties of the words presented at each serial position to ensure comparability across the list. Words were analysed for the variables of Imagery, Concreteness, and Word Frequency. The Shapiro–Wilk test was used to assess the normality of the distributions at each serial position within each variable. For Imagery, the results indicated significant deviations from normality in most positions: Position 1, $W(54) = 0.915$, $p < .001$; Position 3, $W(54) = 0.949$, $p = .022$; Position 5, $W(54) = 0.941$, $p = .010$; Position 6, $W(54) = 0.948$, $p = .020$; and Position 9, $W(54) = 0.941$, $p = .010$. Positions 2, 4, 7, and 8 did not show significant deviations from normality (ps > .05), suggesting approximate normality at these positions. Similarly, for Concreteness, the Shapiro–Wilk test indicated significant deviations from normality at all positions: Position 1, $W(54) = 0.931$, $p = .004$; Position 2, $W(54) = 0.945$, $p = .016$; Position 3, $W(54) = 0.881$, $p < .001$; Position 4, $W(54) = 0.937$, $p = .007$; Position 5, $W(54) = 0.898$, $p < .001$; Position 6, $W(54) = 0.921$, $p = .002$; Position 7, $W(54) = 0.906$, $p < .001$; Position 8, $W(54) = 0.895$, $p < .001$; and Position 9, $W(54) = 0.820$, $p < .001$. For Word Frequency, the Shapiro–Wilk test also indicated significant deviations from normality at all positions: Position 1, $W(54) = 0.664$, $p < .001$; Position 2, $W(54) = 0.523$, $p < .001$; Position 3, $W(54) = 0.722$, $p < .001$; Position 4, $W(54) = 0.502$, $p < .001$; Position 5, $W(54) = 0.320$, $p < .001$; Position 6, $W(54) = 0.687$, $p < .001$; Position 7, $W(54) = 0.575$, $p < .001$; Position 8, $W(54) = 0.446$, $p < .001$; and Position 9, $W(54) = 0.564$, $p < .001$. These results suggest that the distributions for Concreteness and Word Frequency deviated significantly from normality across all serial positions, while Imagery scores showed approximate normality at some positions but not others.

Given that most variables significantly deviated from normality, non-parametric tests were conducted. Separate Friedman tests were performed to examine differences across the nine word positions for Imagery, Concreteness, and Word Frequency. For Imagery, the Friedman test did not show a statistically significant difference across the nine positions, $\chi^2(8) = 10.547$, $p = .235$. Similarly, for Concreteness, no statistically significant difference was found, $\chi^2(8) = 11.662$, $p = .167$. Again, for Word Frequency, the Friedman test indicated no significant difference across positions, $\chi^2(8) = 6.132$, $p = .632$. These results suggest that Imagery, Concreteness and Word Frequency remained relatively consistent across the nine word positions.

2.3.2 Proactive interference

Before we go on to analysis of the complete data, it may be advisable to examine the impact of proactive interference. It may be possible to strengthen the conclusions drawn about PI later on in the study by examining performance ONLY on list 1 of this experiment (before PI has a chance to build up) and drawing some preliminary conclusions. Therefore, only set 1 of all three ISI conditions is examined here graphically. The first set that all participants were shown is the Increasing free recall condition, followed by the decreasing free recall condition and then the irregular free recall condition.

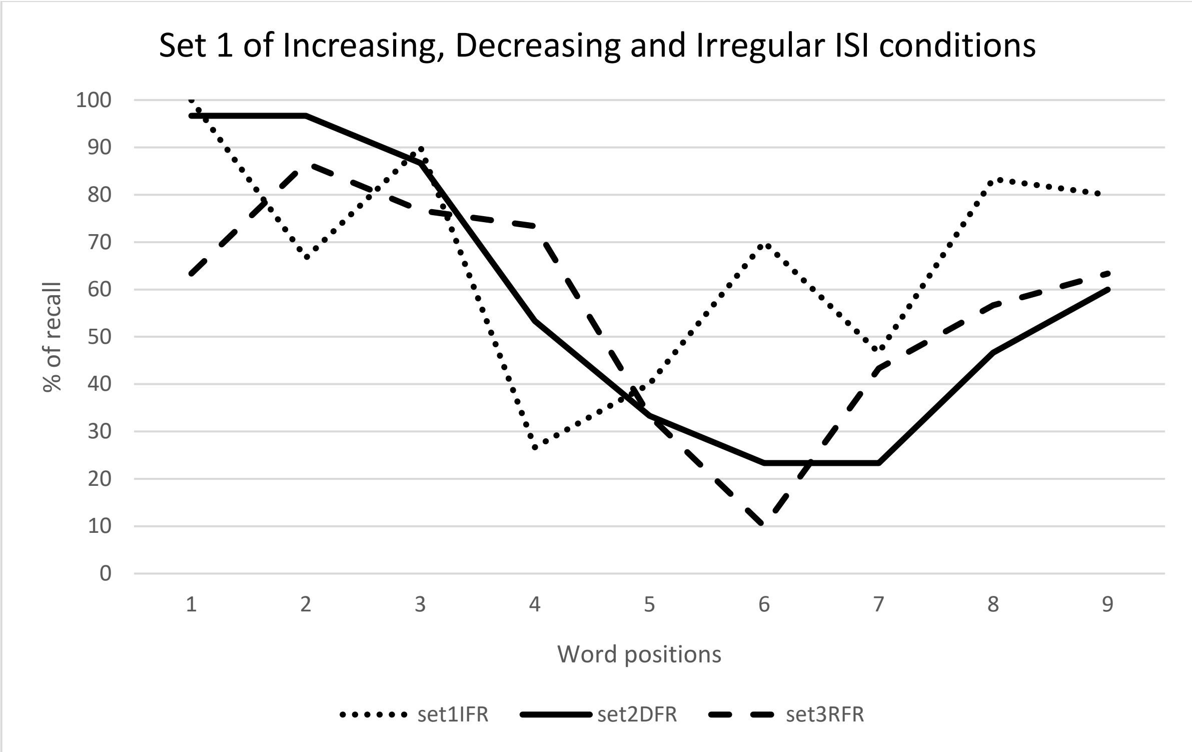

Figure 2.3 Set 1 of Increasing, Decreasing and Irregular ISI conditions as a function of percentage recalled.

As can be seen in Figure, there is a slight advantage of the first set (increasing free recall in overall percentage of items recalled. However, the trend of the increasing free recall condition is very variable. Even though, the overall percentage of items recalled is slightly lower in the decreasing free recall condition, the trend still shows the impact of temporal isolation. This will be examined further when analysing the full dataset. However, given what we know regarding the impact of proactive interference, and the results of the present experiment, it may be beneficial to explore reducing the proactive interference if possible.

2.3.3 Results of word recall across conditions

Items were scored as correct irrespective of the position within the list of nine items. Results were calculated as the number of times each serial position was recalled in a given trial by each participant; in other words, the frequency of recall was calculated for each serial position. A Temporal Isolation Variable (TIV) was calculated as the sum of the distances in milliseconds of an item from its immediate neighbours, and these data for the different ISI schedules and the separate conditions (both free and serial recall) are shown in the figures below. Necessarily, the scores were omitted for the beginning and end items (since a temporal spacing calculation could not be made for these items), so the abscissa in these figures spans 1–7 items.

A repeated-measures ANOVA with a Greenhouse-Geisser correction and factors of word position (seven levels), item lag condition (three levels), and recall condition (two levels) revealed reliable main effects of word position, $F(1.73, 50.34) = 32.80$, $MSe = 18.63$, $p < .001$, $\eta p^2 = .53$, item lag condition, $F(2, 58) = 24.43$, $MSe = 2.02$, $p < .001$, $\eta p^2 = .45$, and recall condition, $F(1, 29) = 117.04$, $MSe = 1.36$, $p < .001$, $\eta p^2 = .80$. The analysis also showed significant interactions between word position and item lag condition, $F(12, 348) = 18.98$, MSe

$= 1.99$, $p < .001$, $\eta p^2 = .39$, between word position and recall condition, $F(3.41, 99.01) = 4.60$, $MSe = 5.27$, $p < .001$, $\eta p^2 = .13$, and between recall condition and item lag condition, $F(2, 58) = 9.29$, $MSe = 1.72$, $p < .001$, $\eta p^2 = .24$. In addition, there was a significant three-way interaction among word position, item lag condition, and recall condition, $F(7.74, 224.49) = 2.89$, $MSe = 3.05$, $p < .001$, $\eta p^2 = .09$.

Post hoc tests using the Bonferroni correction revealed that word 2 (M = 6.10, SD = 0.16) was recalled significantly more than word 3 (M = 5.02, SD = 0.20), $t(29) = 5.71$, $p < .001$, word 4 (M = 4.60, SD = 0.22), $t(29) = 6.94$, $p < .001$, word 5 (M = 3.48, SD = 0.21), $t(29) = 9.82$, $p < .001$, word 6 (M = 3.48, SD = 0.21), $t(29) = 9.78$, $p < .001$, word 7 (M = 3.61, SD = 0.24), $t(29) = 9.52$, $p < .001$, and word 8 (M = 4.58, SD = 0.27), $t(29) = 5.78$, $p < .001$. No other differences between serial positions were found. Therefore, it can be inferred that word position has a robust effect on recall and that words earlier in the list are more likely to be recalled. The post hoc analysis also revealed that the free recall condition (M = 4.75, SD = 0.16) resulted in better performance compared to the serial recall condition (M = 4.04, SD = 0.15), $t(29) = 10.82$, $p < .001$. Additionally, pairwise comparisons between the fixed irregular ISI, increasing ISI, and decreasing ISI conditions showed that recall was significantly better in the fixed irregular ISI condition (M = 4.79, SD = 0.18) compared to the increasing ISI condition (M = 4.22, SD = 0.14), $t(29) = 4.46$, $p < .001$, and the decreasing ISI condition (M = 4.17, SD = 0.16), $t(29) = 4.86$, $p < .001$. No significant difference was observed between the increasing and decreasing ISI conditions, $t(29) = 0.46$, $p = .648$. This pattern suggests that word position and recall condition have stronger effects on recall performance than the manipulation of inter-stimulus intervals. Furthermore, the fixed irregular ISI condition, which served as a control, demonstrated superior performance overall; however, it remains worthwhile to continue exploring how varying the inter-stimulus intervals influences recall, especially considering the interesting results obtained when examining the temporal isolation variable of the different stimuli. Figure 2.4 illustrates the beneficial effect of temporal isolation, as shown by an almost linear positive correlation between recall performance and the last three words with the highest TIV scores across all four conditions.

A paired-samples t-test was used to compare recall between the different item lag conditions (Decreasing ISI, Increasing ISI, and Fixed Irregular ISI) and the different recall conditions (free and serial recall). The results indicated that recall was significantly higher for the Decreasing ISI Free Recall condition (M = 32.56, SD = 7.61) than for the Increasing ISI Free Recall condition (M = 30.56, SD = 6.09), $t(29) = -2.09$, $p = .045$, which is consistent with the pattern observed in Figure 2.3. However, recall was lower for the Decreasing ISI Serial Recall condition (M = 26.20, SD = 6.16) than for the Increasing ISI Serial Recall condition (M = 28.80, SD = 5.22), and a repeated-measures t-test confirmed that this difference was significant, $t(29) = 3.55$, $p = .001$. These results suggest that although the item lag condition influences recall, the recall condition (whether free recall or serial recall) exerts a stronger influence on performance. In addition, significantly better recall was observed for all fixed irregular conditions (both free and serial recall) compared to both the increasing and decreasing ISI conditions.

The figures also show a similar picture. Note that performance in the increasing serial recall (ISR) and decreasing serial recall (DSR) conditions differ, with that for DSR being somewhat lower. Further, recall performance in the fixed irregular time interval conditions (RFR and RSR) appears to be higher than both increasing and decreasing conditions. Also, as shown in Fig. 2.4, in all the conditions, free recall performance was somewhat higher than serial recall. The increasing ISI conditions (IFR and ISR) did not reveal strong effects of temporal isolation and only had average recall (3 – 6) for all the words. The decreasing ISI conditions (DFR and DSR), on the other hand, do appear to show effects of temporal isolation in higher recall for word 2 and 3 (7 - 5) as these were the items that had a higher TIV.

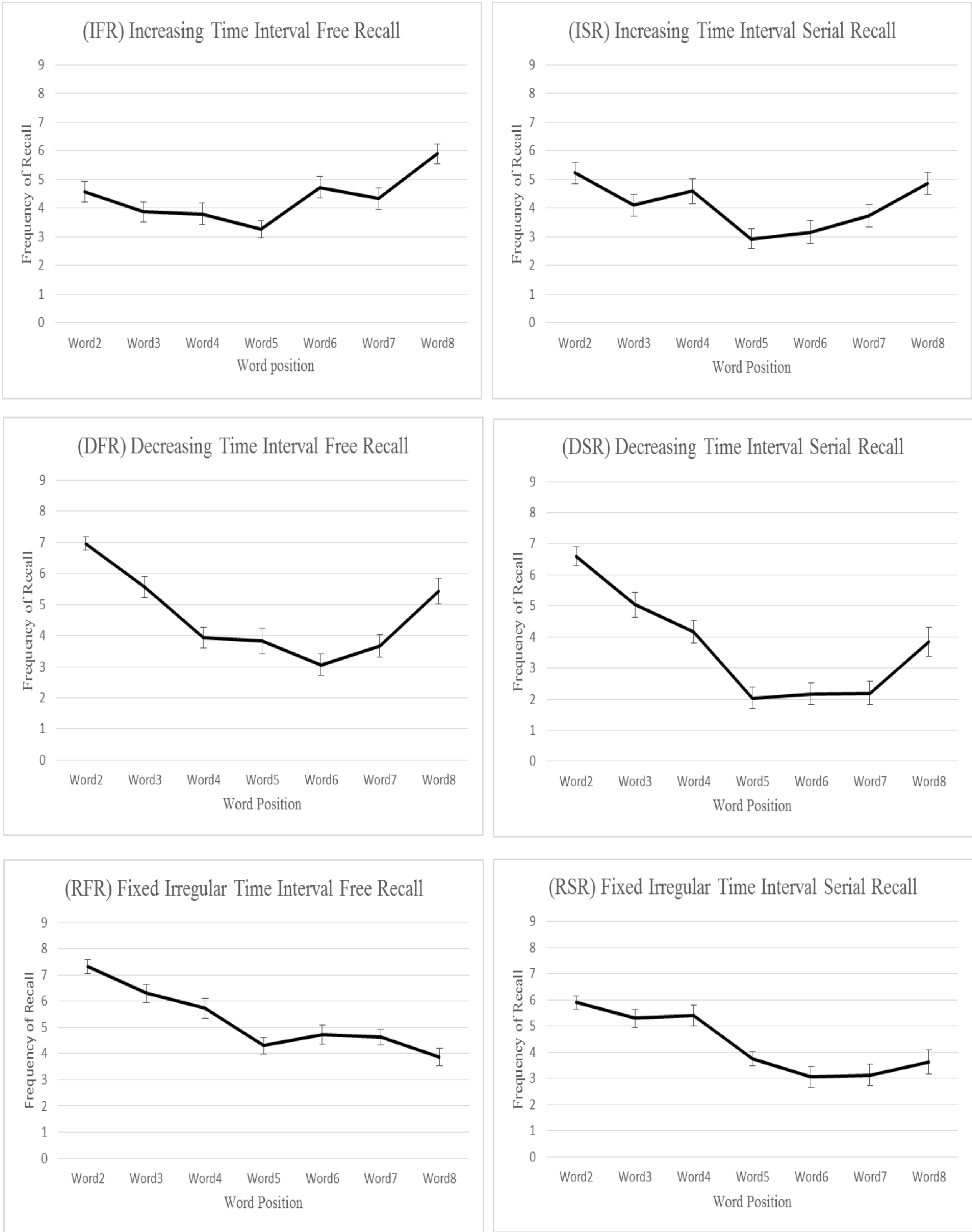

Figure 2.4 Mean frequency of words recalled in the different conditions with standard error bars. The left hand panels show Increasing, Decreasing and Fixed Irregular conditions for Free Recall and the right hand panels show the same for Serial Recall.

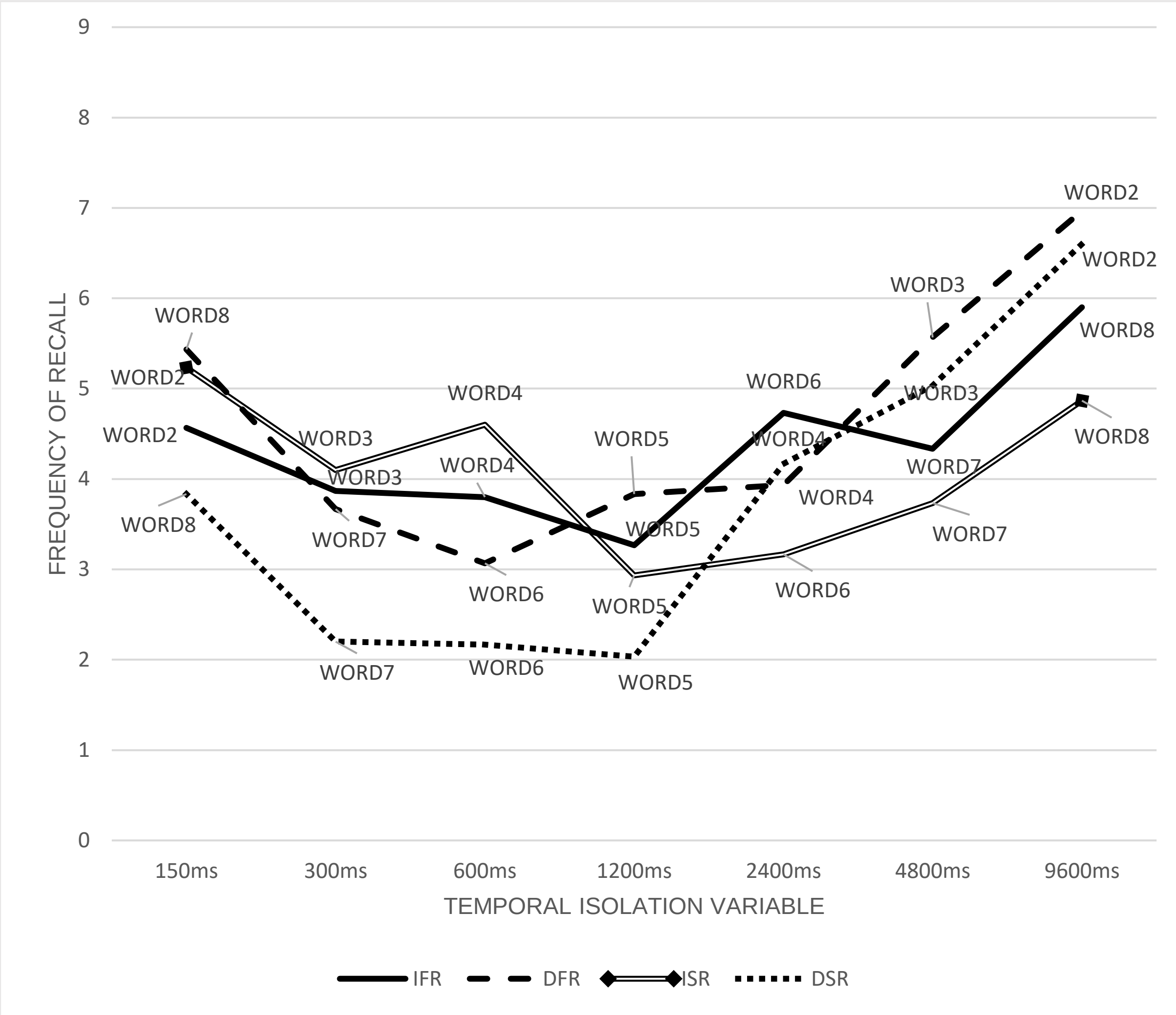

Figure 2.5 Mean frequency of recall as a function of Temporal Isolation Variable for the different word positions.

2.3.1 Temporal Expansion

The increasing ISI condition is referred to as temporal expansion (Fig. 2.5). If the assumption regarding logarithmic spacing of time and in turn, memory distortion is correct, this condition would force or emphasise the negative effects of compression within the memory representation and therefore would be most disadvantageous to recall.

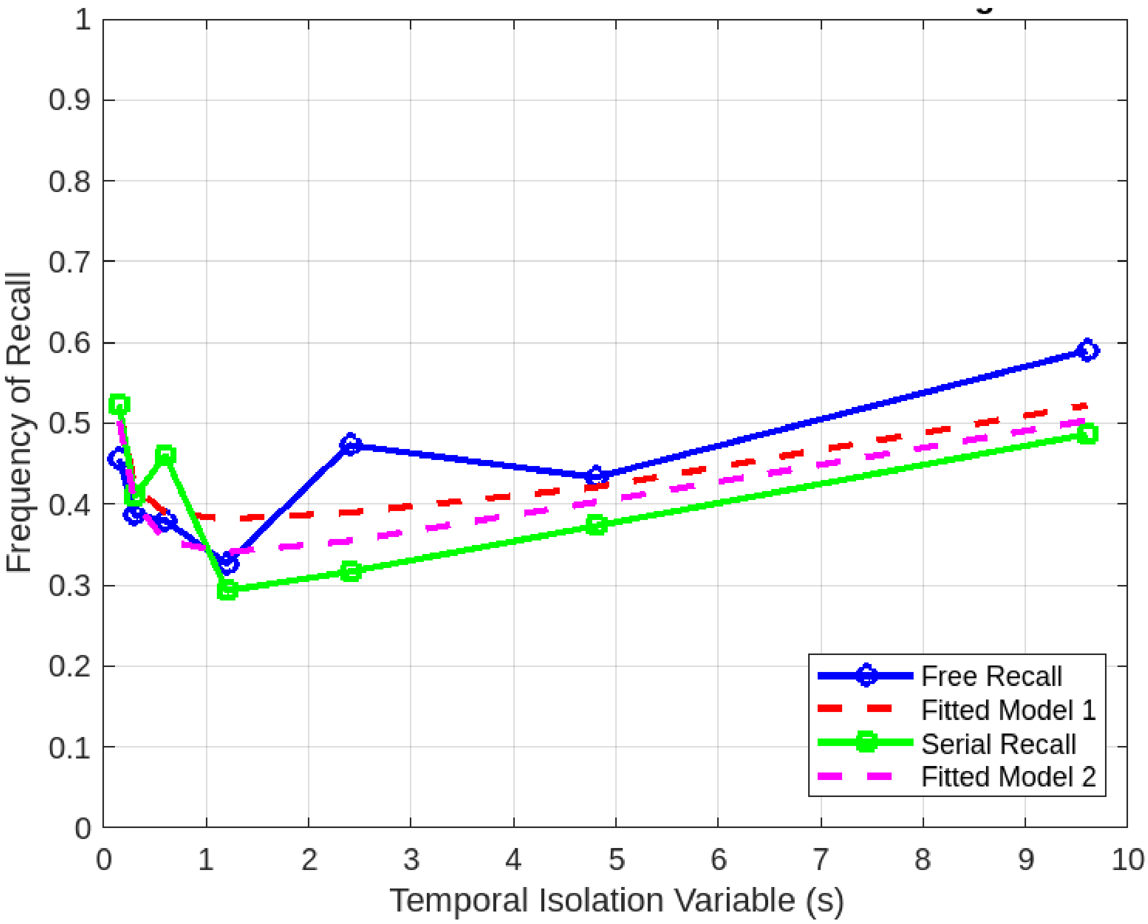

Figure 2.6 Temporal Expansion[1] - Free and Serial recall data fit to SIMPLE model for Increasing ISI Condition

The recall data collected under Free Recall and Serial Recall conditions was simulated using the SIMPLE model to evaluate the fit. The goal is to assess how well the model explains the observed variance in recall frequencies across different temporal isolation intervals. Two datasets were analysed in this study: one representing Free Recall and the other Serial Recall. Each dataset comprised recall frequencies across seven temporal isolation intervals (0.15s to 9.6s). The SIMPLE model was employed to predict recall probabilities based on the temporal distinctiveness of items. The model includes three key parameters: a distinctiveness parameter (c), a slope parameter for the logistic function (slope), and a recall threshold (thresh). Parameters were estimated using the fminsearch optimization function in MATLAB, which minimizes the sum of squared differences between observed and predicted recall probabilities. Initial parameter values were set at c = 0.5, slope = 20, and thresh = 0.2 for both datasets. The SIMPLE model provided a moderate fit to both datasets, with R^2 values of 0.5275 for the Free Recall data and 0.6356 for the Serial Recall data. These values indicate that the model explains approximately 52.75% and 63.56% of the variance in the respective datasets. Figure 2.6

illustrates the observed recall frequencies alongside the predicted values from the SIMPLE model for both Free Recall and Serial Recall conditions. The model captures the general trend but shows discrepancies, particularly at lower temporal isolation intervals. While the SIMPLE model effectively captures the overall trend in recall frequencies, the moderate R^2 values suggest that additional factors, possibly related to encoding variability or interference effects, may influence recall performance under these conditions. The slightly better fit of the SIMPLE model to the Serial Recall data may suggest that temporal distinctiveness plays a more prominent role in this condition compared to Free Recall, where other factors such as reduced cognitive load may contribute more significantly. In summary, the SIMPLE model provides a moderate explanation for recall frequencies under both Free Recall and Serial Recall conditions, with a slightly better fit for the latter. These findings highlight the role of temporal distinctiveness in memory recall but suggest the need for more comprehensive models to capture the full range of influencing factors. The MATLAB code utilised in the simulation is provided in the appendices.

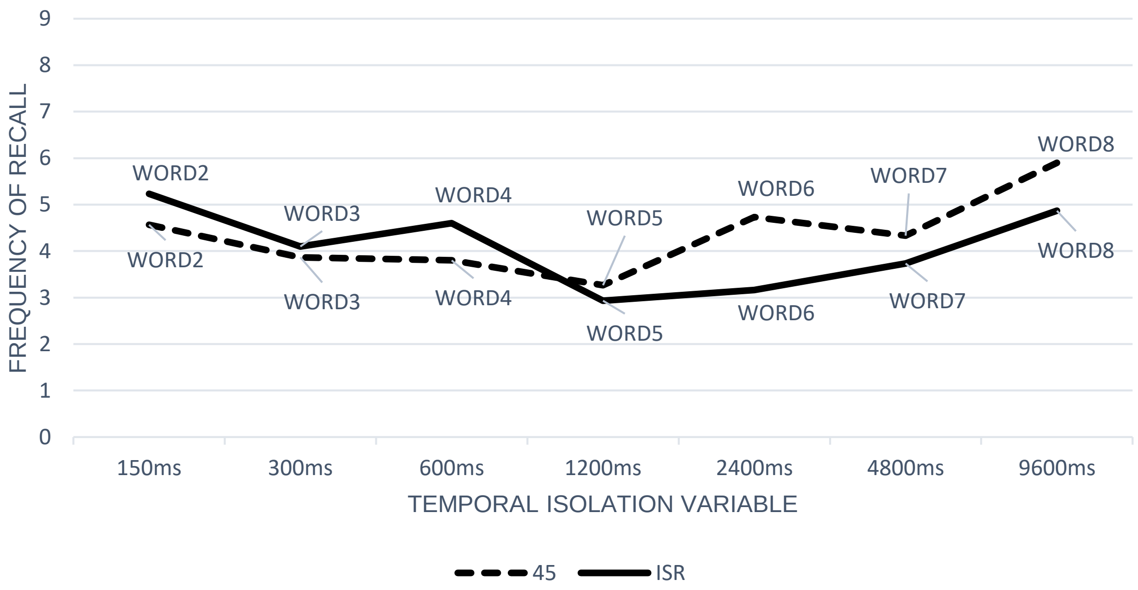

Figure 2.7 Increasing Free Recall and Increasing Serial Recall (Temporal Expansion)

Fig. 2.7 shows that the results are broadly as predicted: performance in both free and serial recall in the increasing ISI condition is on average low (3 – 6). The increasing ISI condition leads to poorer performance overall especially in free recall.

2.3.2 Temporal Contraction

Conversely, the decreasing ISI condition is referred to as temporal contraction. This is the more interesting condition and crucial to the basic assumption of the present theoretical conjecture. This stimulus schedule should effectively negate or reverse the psychological compression within the memory trace.

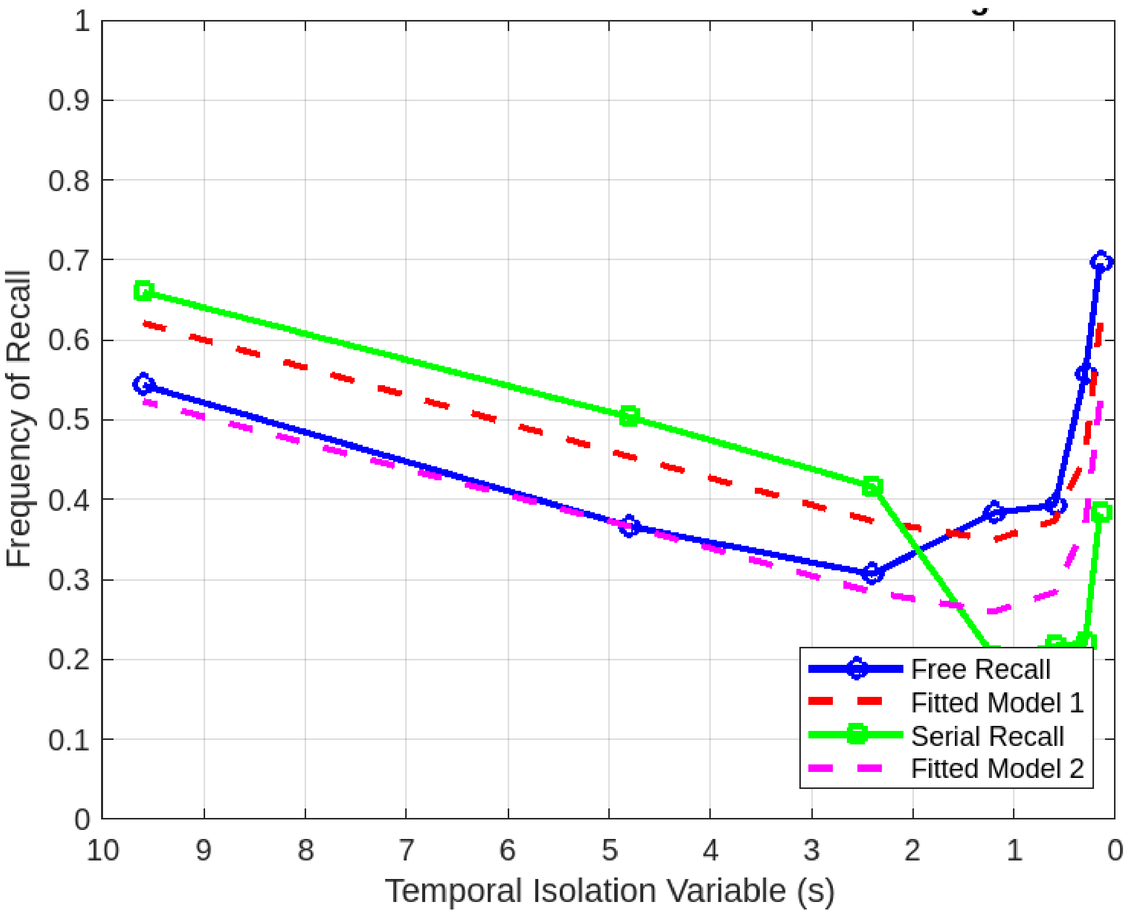

Figure 2.8 Temporal Contraction – Free and Serial recall data fit to SIMPLE model for Decreasing ISI Condition

The aim is to examine the goodness of fit to the SIMPLE model in predicting recall performance under a Decreasing ISI condition. In this condition, the time between item presentations was progressively reduced, potentially affecting the temporal distinctiveness of items and their recall likelihood. Two datasets were analysed: Free Recall and Serial Recall, both consisting of recall frequencies measured across seven Temporal Isolation Variables (TIV) ranging from 9.6 seconds to 0.15 seconds. The ISI was systematically decreased, affecting the TIV and expected recall outcomes. The SIMPLE model was fitted to both datasets with initial parameter estimates set at c = 0.5, slope = 20, and thresh = 0.2. Model parameters were optimized using the fminsearch function in MATLAB, which minimizes the sum of squared differences between observed and predicted recall probabilities. The SIMPLE model provided a moderate fit to both datasets, with R^2 values of 0.68727 for the Free Recall data and 0.41715 for the Serial Recall data. These values indicate that the model explains approximately 68.72% and 41.71% of the variance in the respective datasets. Figure 2.8 illustrates the observed recall frequencies and their respective SIMPLE model predictions. The model successfully captures the general downward trend in recall as TIV decreases, particularly for

Free Recall. However, it underestimates the sharp increase in recall observed at the lowest TIV values, especially in the Serial Recall dataset. The superior fit of the SIMPLE model to the Free Recall data suggests that temporal distinctiveness plays a significant role in this task, even under decreasing ISI conditions. In contrast, the lower R^2 value for Serial Recall indicates that additional factors, perhaps related to the fixed order of item presentation, may influence recall more strongly in this task. The model’s underestimation of recall at the lowest TIV values suggests that it may not fully account for the cognitive mechanisms at play when temporal intervals are compressed. Future research could explore modifications to the SIMPLE model that incorporate variable encoding rates or adaptive threshold mechanisms to better capture these dynamics. The SIMPLE model demonstrated a good fit for Free Recall under the Decreasing ISI condition, while its performance was more limited for Serial Recall. These results highlight the importance of temporal distinctiveness in Free Recall but suggest that additional factors must be considered for Serial Recall. The MATLAB code utilised in the simulation is provided in the appendices.

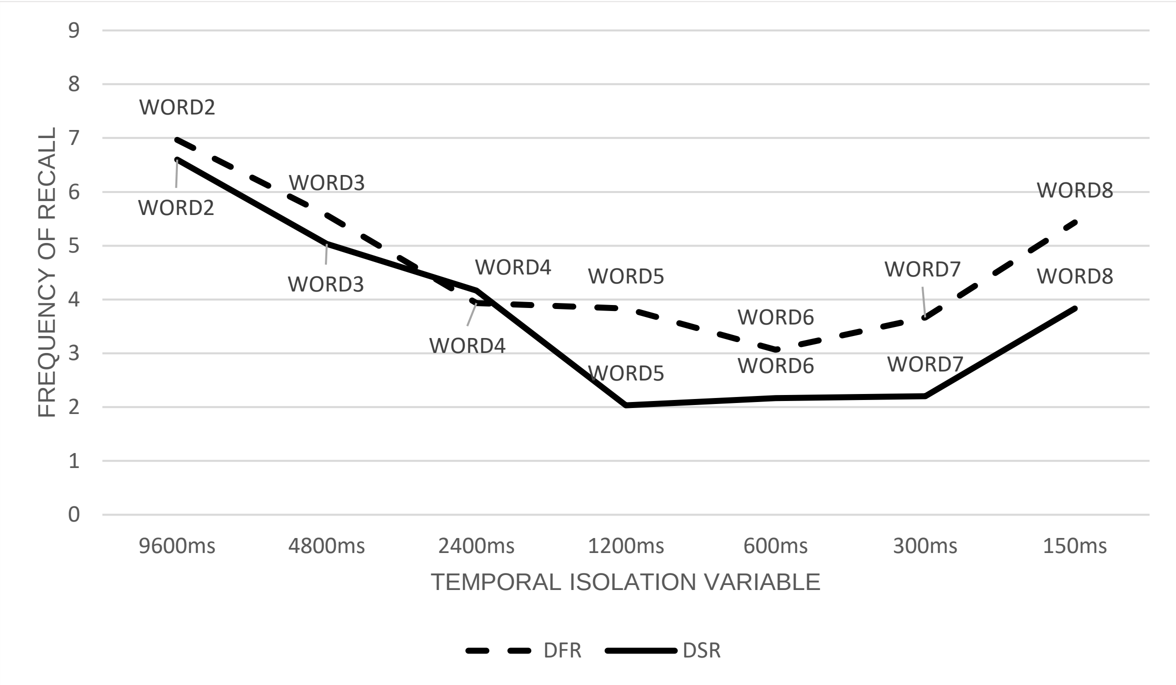

Figure 2.9 Decreasing Free Recall and Decreasing Serial Recall (Temporal Contraction)

As can be seen from Fig. 2.8, although the decreasing ISI condition does not negate the effect completely (render the serial position curve flat), nevertheless it does have a significant beneficial effect on performance in both recall conditions, especially so in the free recall condition.

The parameter estimates obtained from the SIMPLE model fitting provide important insights into how recall performance is influenced by temporal isolation under different ISI manipulations. Across both Increasing and Decreasing ISI conditions, the distinctiveness parameter (c) was initialized at 0.5, reflecting the participants’ sensitivity to differences in temporal separation between items. The moderate values of c observed across both simulations suggest that temporal distinctiveness influenced retrieval decisions, but that participants were not operating at maximum sensitivity to isolation differences. Rather, distinctiveness appeared to contribute alongside other cognitive factors. The slope parameter, initially set at 20, governed the sharpness of the transition between low and high recall probabilities based on distinctiveness. The relatively steep slope found in both conditions indicates that once an item crossed a certain distinctiveness threshold, participants were highly likely to recall it, reflecting a relatively categorical, all-or-none recall process. In psychological terms, this suggests that recall was not a smooth gradient based on increasing distinctiveness but instead exhibited a thresholded effect, where sufficiently distinct items were reliably accessed, and less distinctive items were largely omitted.

However, differences in the SIMPLE model's goodness-of-fit between the two ISI conditions were notable. Under the Increasing ISI condition, the model explained a moderate proportion of variance for Free Recall ($R^2 = 0.5275$) and Serial Recall ($R^2 = 0.6356$). In contrast, under the Decreasing ISI condition, model fit improved for Free Recall ($R^2 = 0.6873$) but declined substantially for Serial Recall ($R^2 = 0.4172$). These differences highlight the important role of temporal dynamics in shaping memory retrieval. In the Increasing ISI condition, where intervals progressively lengthened, the growing separation between items likely enhanced the discriminability of temporal contexts, leading to more distinct memory traces and supporting the SIMPLE model's assumptions. Here, participants could rely heavily on temporal distinctiveness cues, consistent with the model's core mechanisms.

Conversely, in the Decreasing ISI condition, where intervals progressively shortened, temporal distinctiveness would have been higher early in the list but increasingly compressed toward the end. This compression likely introduced greater interference among item representations, disrupting the distinctiveness gradient necessary for effective retrieval based purely on temporal cues. In Serial Recall, where item-to-item order is crucial, compressed intervals may have placed greater demands on organizational strategies, positional coding, or rehearsal mechanisms rather than pure temporal distinctiveness, which the SIMPLE model does not directly model. Thus, the poorer model fit for Serial Recall under Decreasing ISI conditions suggests that when temporal distinctiveness cues weaken, participants may shift toward alternative retrieval strategies that emphasize order or relational information rather than distinctiveness per se.

Additionally, under Decreasing ISI, the model systematically underestimated recall performance at the shortest TIVs. Psychologically, this suggests that participants may adaptively modify their encoding strategies or retrieval thresholds under rapid presentation conditions. For instance, participants might prioritize attentional resources more narrowly, adopt chunking strategies, or lower the distinctiveness threshold necessary for attempting recall when faced with tightly compressed item presentation. Such adaptive behaviour highlights human flexibility in memory encoding and retrieval processes—flexibility that static, distinctiveness-based models like SIMPLE currently do not accommodate.

Overall, these results emphasize that while temporal distinctiveness is a powerful cue for retrieval, its influence is highly context-dependent, shaped by dynamic changes in temporal structure across the study list. They also suggest the need for memory models that incorporate adaptive encoding mechanisms, variable threshold adjustment, and alternative retrieval strategies to fully capture the complexities of recall performance under changing temporal constraints.

In summary, the SIMPLE model provided a moderate account of recall performance under both Increasing and Decreasing ISI conditions, with better fits observed when temporal isolation expanded across the list. Model parameters suggested that recall was driven by moderate sensitivity to temporal distinctiveness and relatively categorical retrieval decisions.

The model performed less well under Decreasing ISI, particularly for Serial Recall, likely due to compressed intervals disrupting distinctiveness gradients and encouraging alternative retrieval strategies. These findings highlight that recall is influenced not only by temporal distinctiveness but also by participants' adaptive responses to changing temporal structures.

Fig. 2.9.1 plots recall performance in the Fixed Irregular ISI control condition for both free and serial recall. Looking at the figure, we notice that there are no noticeable dips or peaks and, although we may note beneficial signs of the effect of temporal isolation (higher recall of the word 5 and word 4, they being the items with the highest TIV). Where we have seen moderate to low performance for these two item positions elsewhere in the experiment (increasing and decreasing ISI conditions), here we see significantly higher performance for them.

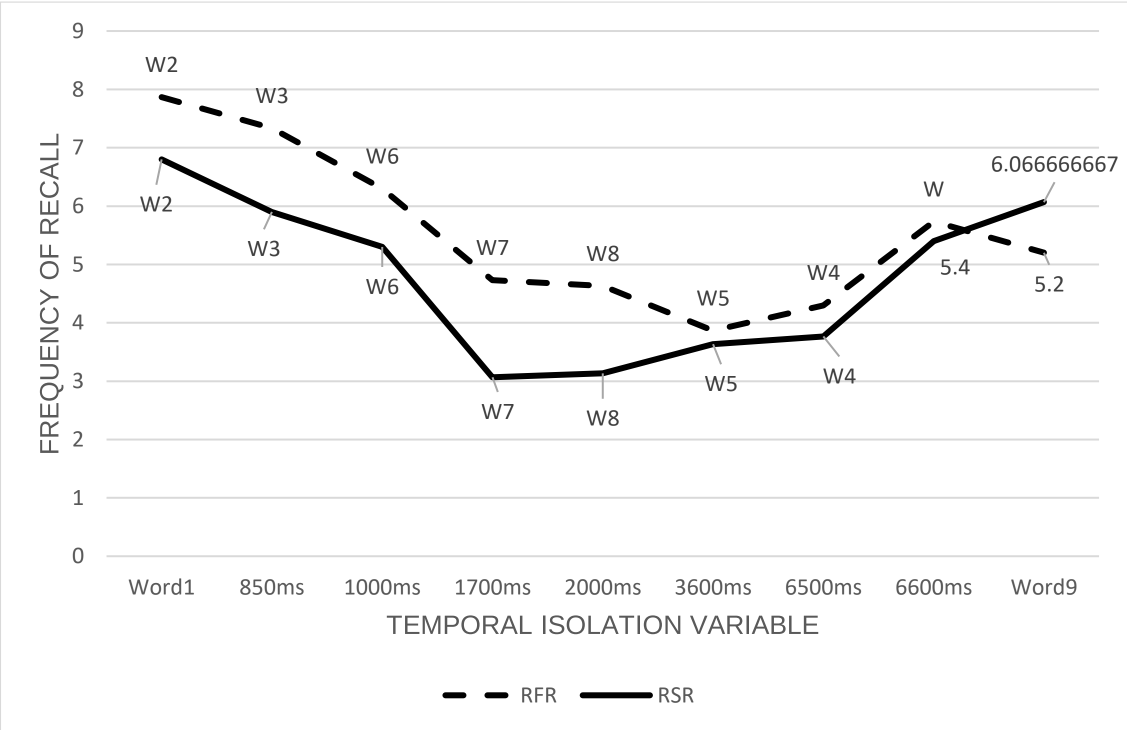

Figure 2.9.1 Fixed Irregular Free Recall and Fixed Irregular Serial Recall.

2.4 Items 1 and 9

Recall that items 1 and 9 had to be considered separately from the rest of the stimuli in the list because a TIV calculation could not be made for these items. On all the schedules and the two different conditions, the mean frequency of recall for item 1 was approximately 7.3 and for item 9, it was approximately 6. There was not much variability in the frequency of recall for item 1 except a higher than average recall for the DSR condition and this may be because in this condition, not only does item 1 have to be recalled first but it also has a higher temporal isolation (it is after all succeeded by an extended inter-trial interval).

2.5 Discussion

As previously explained, participants were exposed to the free recall condition before moving on to the serial recall condition. This may have had an impact on the encoding strategies as well as retrieval strategies. When a set of free recall tasks is followed by a set of serial recall tasks, several cognitive and memory processes come into play, influencing recall performance. These processes can be understood and predicted by integrating various theoretical models of memory, including the temporal distinctiveness model, interference theory, and the dual-store model.

According to interference theory, proactive interference is likely to occur when participants switch from free recall to serial recall (Crowder, 1976). The flexible retrieval strategies developed during free recall, where items are recalled in any order, may interfere with the ordered retrieval required in serial recall. This interference occurs because the memory traces and associations formed during free recall might conflict with the demand to recall items in the exact sequence in the serial recall tasks. Additionally, the transition from free recall (where retrieval is unconstrained and can be influenced by semantic or temporal clustering) to serial recall (which requires strict adherence to the original order of presentation) may create a cognitive challenge. According to the dual-store model (Atkinson & Shiffrin, 1968), the requirement to switch from a primarily long-term retrieval strategy (used in free recall) to a short-term, order-sensitive retrieval strategy (used in serial recall) might cause disruptions, leading to reduced accuracy in serial recall. As was seen on the graphical representation of the analysis of the first list in each ISI condition, there is a slight advantage of the first set (increasing free recall) in overall percentage of items recalled. However, the trend of the increasing free recall condition is very variable. Even though, the overall percentage of items recalled is slightly lower in the decreasing free recall condition, the trend still shows the impact of temporal isolation. This will be examined further when analysing the full dataset. However, given what we know regarding the impact of proactive interference, and the results of the present experiment, it may be beneficial to explore reducing the proactive interference if possible.

It is also worth noting that the temporal distinctiveness model (Brown et al., 2007) suggests that the strong recency effect often observed in free recall might diminish when participants shift to serial recall. In free recall, the most recent items benefit from greater temporal distinctiveness, making them easier to recall. However, in serial recall, the demand for ordered retrieval reduces the advantage of these items, as they are no longer recalled based purely on their distinctiveness but on their position in the sequence.

Switching from a set of free recall tasks to serial recall can increase cognitive load due to the different retrieval demands. Cognitive load theory suggests that the mental effort required to adapt to these differing tasks might lead to fatigue, potentially reducing recall accuracy in the serial recall tasks, especially as the demands on attention and memory resources increase. The working memory model (Baddeley & Hitch, 1974) highlights the role of limited cognitive resources in managing task demands. As participants switch from free recall to serial recall, the increased demand on working memory to maintain the order of items might lead to errors, particularly if cognitive resources are depleted from the earlier tasks.

As the stimuli were not randomly selected, the psycholinguistic properties of the verbal stimuli selected were analysed retrospectively. The analysis revealed that although the psycholinguistic properties were not significantly different across the different ISI conditions (increasing, decreasing and irregular ISI), the scores for imagery and concreteness were significantly higher in the free recall conditions than in the serial recall condition. We already know that the cognitive load is lower in the free recall condition and having verbal stimuli with higher imagery and concreteness would have likely added an advantage to recall. However, this would still not prevent us from drawing conclusions about the impact of temporal isolation and different ISI schedules on recall.

The results of this first experiment are encouraging, revealing a statistically significant benefit of temporal isolation of items in a serially ordered list. The higher recall performance for items having a higher TIV is consistent with some previous studies which also report that temporal isolation has a positive influence on recall (Welte and Laughery, 1971; Bjork and Whitten, 1974; Glenberg and Swanson, 1986) - as long as it is free recall and output order is not specified (Lewandowsky et al., 2008). Furthermore, Decreasing Free Recall (DFR) demonstrated somewhat better performance than the Increasing Free Recall (IFR) which is consistent with the present assumption that applying a ‘negative compression’ will enhance performance. In all four conditions – increasing and decreasing serial and free recall, it can be seen that the words with higher TIV show an increase in recall performance which is consistent with studies that looked at temporal isolation in a *free recall* situation (Brown et al., 2006), and even in a forward serial recall task (Morin et al., 2010). However, certain studies report no significant effect of temporal isolation on *serial recall* when a random stimulus presentation schedule is adopted (Lewandowsky et al., 2008; Lewandowsky et al., 2006; Nimmo and Lewandowsky, 2006; Parmentier et al., 2006). This could either be because temporal isolation effects in serial recall are rather small (as noted by Morin et al. (2010) or it may be that a negative compressive schedule needs to be applied (as used in the present study) so as to better see the effects of temporal isolation in serial recall.

In the Increasing ISI condition, the study observed a tendency for memory compression effects, where longer ISIs led to a decrease in recall performance. This aligns with previous research indicating that temporal expansion can sometimes result in less effective encoding due to reduced recency effects (Craik & Lockhart, 1972). The moderate fit of the recall data to the SIMPLE model ($R^2 = 0.5275$ for Free Recall and $R^2 = 0.6356$ for Serial Recall) suggests that while the model captures some trends, it may not fully account for all nuances in recall performance. This discrepancy highlights the need for models that integrate additional variables, such as encoding strategies and individual differences, to more accurately predict recall outcomes.

Turning to the fixed irregular control condition in the present experiment, Welte and Laughery (1971) reported effects of ‘reduced effort’ in maintaining *later items* in a decreasing temporal schedule where that schedule had high predictability. This indicates that because participants come to expect that in a decreasing schedule, the last few items are temporally crowded, they tend to put in less effort in trying to remember them. An unpredictable control schedule offers some insight into this participant strategy. The high performance for the words with highest TIV in this condition is not only as predicted but also consistent with previous studies that have looked at recall with an unpredictable temporal schedule (Lewandowsky et al., 2006; Lewandowsky et al., 2008; Geiger and Lewandowsky, 2008).

Chapter 3 - The question of articulatory rehearsal and attentional refreshing

3.1 Introduction to Experiment 2

An important feature in the first study was that, across all three item lag conditions, verbal recall was higher for items with higher temporal isolation. In other words, a significant beneficial effect of temporal isolation on recall of verbal stimuli was established. However, it is well known that when utilising verbal stimuli for memory experiments, one has to account for sub-vocal or verbal rehearsal. In the first experiment, a worrying confound of increasing the temporal intervals between verbal stimuli is permitting more time for verbal rehearsal. Verbal rehearsal or articulatory rehearsal has been found to have a significant positive influence in immediate verbal memory as described in Baddeley's model (Baddeley and Hitch, 1974; Engle et al., 1999). Baddeley's model suggests that verbal information is stored a short-term phonological store with auditory memory traces that are subject to rapid decay but an articulatory rehearsal component can revive the memory traces. The assumption is that participants may be actively rehearsing the verbal stimuli during the temporal intervals so that any observed increase in recall may not be due to temporal isolation alone. Necessarily, an extended temporal interval without any distractors can also confound or even enhance performance by allowing verbal memory traces to remain active by repeatedly 'refreshing' the items presented. This phenomenon of attentional refreshing of the memory traces through attentional focusing was outlined in Introduction (Barrouillet and Camos, 2001; Barrouillet et al., 2004; Miyake and Shah, 1999; Cowan, 2005).

It is, therefore, important to address these confounds and analyse the extent to which they impacted the results obtained in the first study. One solution would have been to not use verbal stimuli at all and instead use visual or abstract non-verbal stimuli that do not lend themselves to easy verbal encoding (for example, a letter or a character from an unfamiliar language). The reader will see that this strategy has been adopted in the experiments to be reported in later chapters. But in the present experiment, verbal memoranda were still of interest, not least for allowing comparison with existing studies where differing temporal spacing schedules have been examined (such as by Neath et al., 1990; 1996). However, if verbal stimuli were to be used, the usual solution to control for the confounding factors of articulatory maintenance - articulatory suppression or repetition of irrelevant verbal articulations between presentations of to-be-remembered verbal stimuli – was adopted (for example, Murray, 1968). Similarly, to prevent attentional refreshing, tasks that increase the concurrent demands on attention can be used to intervene with attentional focus on the to-be-remembered stimuli (Barrouillet et al., 2004; Barrouillet et al., 2007); so in the present experiment, cognitively demanding tone discrimination tasks were used between the presentation of memoranda.

The present study therefore addresses the questions of articulatory rehearsal and attentional refreshing within the memory retention intervals, whilst also being a refinement and attempted replication of the first study. It offers a chance not only to replicate our findings about the (modest) beneficial effect of temporal isolation but also the beneficial effect of the decreasing ISI schedule on recall. Methodology is similar to Experiment 1 with the distinction that the temporal intervals between the verbal stimuli were filled to control for verbal rehearsal by repeating a nonsense word and attentional refreshing by simple tone discrimination tasks. Participants were divided into two groups – a Rehearsal group – controlling for articulatory rehearsal and a Refreshing group - controlling for attentional refreshing. Additionally, the fixed irregular ISI condition, whilst it served its purpose as control by decreasing the predictability of the schedule in the earlier experiment, was replaced with a regular equal ISI condition (this is after all a more widely used control condition in prior studies).

Another important adjustment made was the addition of START and STOP items. The reader may recall that, in the first experiment, the temporal interval or spacing calculation could only be calculated for items between the first and last item. Therefore, in Experiment 2, the first item was replaced with START and the last with STOP; data are only be reported for the series of items between these words (7 words). It will be seen later in the Chapter that the introduction of START and STOP alone did not eliminate the problem of calculating the appropriate temporal isolation variable. Unfortunately, a critical factor in the spacing schedule was unintentionally omitted from consideration because even though START and STOP items were introduced, inter-stimulus intervals between START and the first item and the last item and STOP did not conform precisely to the intended logarithmic spacing schedule of increasing, decreasing or equal ISIs (in other words a mistake was made in the spacings). The key experimental prediction, which is now well rehearsed, is that a progressively decreasing schedule of inter-item spacings will be optimum for memory trace encoding.

3.2 Method

3.2.1 Participants.

A total of thirty volunteers (27 females and 3 males) assigned alternately to **Rehearsal group** and **Refreshing group** (15 participants in each group) were recruited from the University of Leeds participant pool in exchange for course credits. The Rehearsal group had an average age of 19 years and the average age for the Refreshing group was 19.4 years. They were native English Speakers, had normal/corrected to normal vision and had not been diagnosed with a neurological problem.

3.2.2 Stimuli.

The stimuli consisted of 378 words taken from the Toronto Word Pool (Friendly et al., 1982) divided into 6 experimental blocks.

3.2.3 Materials and Design.

The experiment was designed on E-prime software similar to the previous experiment. All stimuli were presented on the centre of the screen, in a 60- point Arial font for 1000ms. They were then given a response sheet to record their responses. Each of the 6 experimental blocks consisted of 9 sets of 7 words each not including START and STOP. The Inter-stimulus interval (ISI) between individual words was manipulated to create three item lag conditions as shown in Fig. 3.1 - increasing ISI with 200, 400, 800, 1600, 3200 and 6400ms ISIs from Word 1 to 7; decreasing ISI with 6400, 3200, 1600, 800, 400, 200 ISIs from Word 1 to 7; equal ISI with 2700ms ISIs from Word 1 to 7. In each set, between START and STOP and the adjacent word there was an ISI of 100ms. Participants were divided into two groups. They were allotted to groups alternately, e.g. Participant 1 in group Rehearsal, Participant 2 in group Refreshing, Participant 3 in group Rehearsal and so forth. The Rehearsal group controlled for articulatory rehearsal; the Refreshing group controlled for attentional refreshing. Thus, a mixed experimental design was employed with factors of lag (within) and distractor task (between).

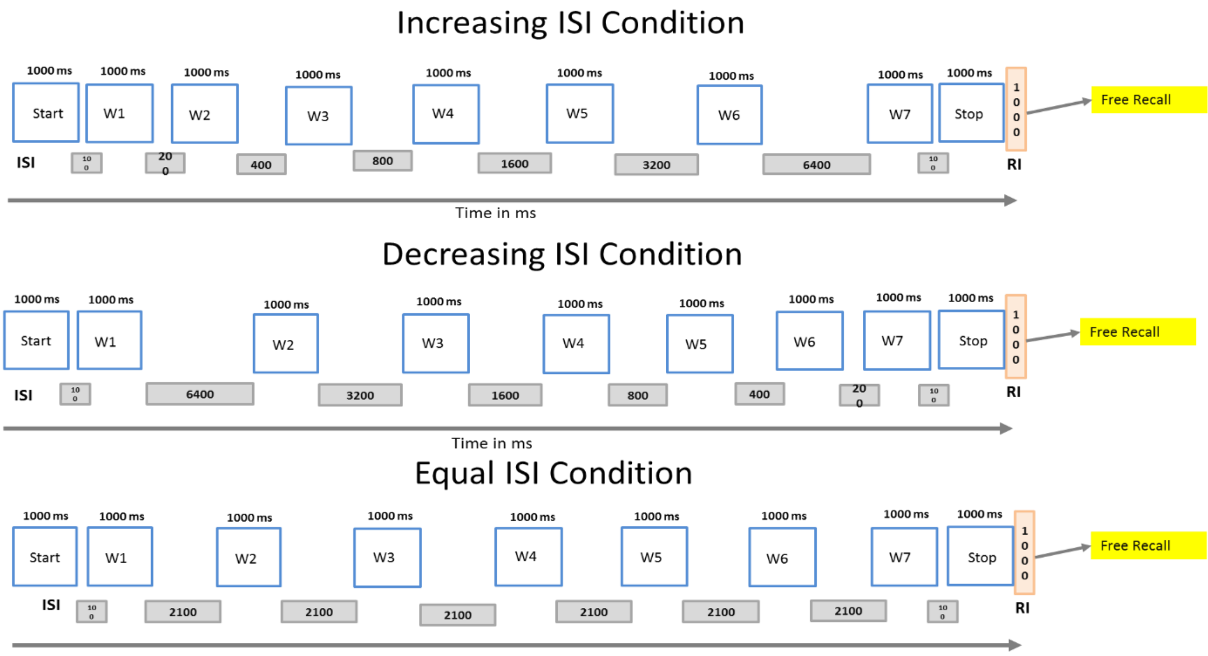

Figure 3.1 Inter Stimulus Intervals (ISI) in the three item lag conditions (Increasing ISI, Decreasing ISI and Equal ISI) in Experiment 2

3.2.4 Procedure.

Participants completed a simple computer administered verbal recall task consisting of 6 experimental blocks. As shown in Fig. 2.2, this meant there were 18 trials per item lag condition. Unknown to the participants, the inter-stimulus interval (ISI) between individual words was manipulated to create three item lag conditions (increasing ISI, decreasing ISI and varying ISI). Each block had 9 sets of 7 words (not including START and STOP) each with alternating increasing, decreasing and equal ISI schedules starting with the increasing ISI schedule for every block for every participant.

Of the six experimental blocks, the first three blocks involved no distraction between the words for either group. This served as the control condition and was included to determine whether the findings of the previous study could be replicated. In the second set of three blocks, participants either experienced articulatory suppression, in which they were required to repeatedly say the phrase "coca cola" between the presentations of the words (Rehearsal group), or attentional suppression, in which participants heard pure auditory tones of different frequencies via loudspeakers and were required to press the up or down keys on a handheld device to indicate whether the tone was higher or lower than the preceding tone (Refreshing group).It was explained that each stimulus sequence on a trial began with the word START and ended with the word STOP. Participants were instructed to carefully observe words that were shown on the screen and were informed that they would be asked to recall them in any order (Free Recall) at the end of each set (prompted by the picture of a pen on screen). They were further instructed not to write down these words during the presentation of the words on the screen. In the free recall condition, the participants could write down any word in any row that they wished They were given as much time as required to write down the words they recalled on the response sheet provided. Each experimental block was separated by a break (minimum length of 3 minutes). The experimental session lasted no longer than 55 minutes (including breaks). Participants were tested individually with the experimenter present in the room.

3.3 Results

3.3.1 Psycholinguistic properties of the verbal stimuli

The psycholinguistic properties of the words used in three different ISI conditions (increasing, decreasing and equal ISI) were analysed to ensure comparability across conditions. A total of 378 words were used across three conditions (126 words each) and they were analysed for the variables of Imagery, Concreteness, and Word Frequency as the word length was the same across all the words used in the study (two syllables long). The Shapiro-Wilk test was used to assess the normality of the distributions for each condition within each variable. For Imagery, the results indicated significant deviations from normality in all three conditions: Increasing ISI condition, $W(126) = 0.945$, $p < 0.001$; Decreasing ISI condition, $W(126) = 0.959$, $p < 0.001$; and Equal ISI condition, $W(126) = 0.957$, $p < 0.001$. Similarly, for Concreteness, the Shapiro-Wilk test showed significant deviations from normality in all three conditions: Increasing ISI condition, $W(126) = 0.92$, $p < 0.001$; Decreasing ISI condition, $W(162) = 0.928$, $p < 0.001$; and Equal ISI condition, $W(126) = 0.916$, $p < 0.001$. For Word Frequency, the Shapiro-Wilk test also indicated significant deviations from normality across all conditions: Increasing ISI condition, $W(162) = 0.397$, $p < 0.001$; Decreasing ISI condition, $W(162) = 0.646$, $p < 0.001$; and Equal ISI condition, $W(161) = 0.519$, $p < 0.001$. These results suggest that the distributions for Imagery, Concreteness, and Word Frequency were not normally distributed across the three conditions.

Given that all variables significantly deviated from normality, non-parametric tests (Friedman test and subsequent post hoc tests) were conducted as was done previously. The results of the Freidman test indicated that there was a statistically significant difference in these psycholinguistic properties across the conditions, $\chi^2(8, N = 126) = 477.436$, $p < 0.001$.

Following the significant Friedman test for Imagery, post hoc comparisons using the Wilcoxon signed-rank tests were performed to identify specific differences between conditions. However, none of the pairwise comparisons for Imagery were statistically significant after applying the Bonferroni correction. The comparisons between Increasing ISI condition and Decreasing ISI condition ($Z = -1.52$, $p = 0.129$), Decreasing ISI condition and Equal ISI condition ($Z = -0.94$, $p = 0.348$), and Increasing ISI condition and Equal ISI condition ($Z = -0.71$, $p = 0.480$) all failed to reach significance.

Similarly, Wilcoxon signed-rank tests conducted for Concreteness and Word Frequency revealed no significant differences between any of the conditions. For Concreteness, the comparisons between Increasing ISI condition and Decreasing ISI condition ($Z = -0.45$, $p = 0.652$), Decreasing ISI condition and Equal ISI condition ($Z = -0.97$, $p = 0.331$), and Increasing ISI condition and Equal ISI condition ($Z = -0.86$, $p = 0.390$) were not significant. For Word Frequency, the comparisons between Increasing ISI condition and Decreasing ISI condition ($Z = -1.05$, $p = 0.292$), Decreasing ISI condition and Equal ISI condition ($Z = -0.50$, $p = 0.615$), and Increasing ISI condition and Equal ISI condition ($Z = -0.06$, $p = 0.951$) were also not significant. Therefore, it can be concluded that there were no significant differences in Imagery, Concreteness, and Word Frequency across the three ISI conditions.

The data were analysed for differences in imagery, concreteness, and word frequency across two conditions within each group, ‘without distractor’ ($N = 189$) and ‘with distractor’ ($N = 189$). The mean score for imagery in ‘without distractor’ condition was 4.5 ($SD = 1.49$), and in ‘with distractor’ condition it was 3.89 ($SD = 1.38$). For concreteness, the mean in ‘without distractor’ condition was 4.69 ($SD = 1.53$), and in ‘with distractor’ condition, it was 4 ($SD = 1.29$). Word frequency had a mean of 53.86 ($SD = 87.39$) in ‘without distractor’ condition, and 66.38 ($SD = 103.67$) in ‘with distractor’ condition.

Tests of normality using the Shapiro-Wilk test indicated that the data significantly deviated from a normal distribution for all variables across both conditions. Specifically, the imagery scores significantly deviated from normality in both the ‘without distractor’ condition, $W(189) = 0.942$, $p < 0.001$, and the ‘with distractor’ condition, $W(189) = 0.967$, $p < 0.001$. The concreteness scores also significantly deviated from normality in both the ‘without distractor’ condition, $W(189) = 0.913$, $p < 0.001$, and the ‘with distractor’ condition, $W(189) = 0.914$, $p < 0.001$. Similarly, significant deviations from normality for word frequency scores were also seen in both the ‘without distractor’ condition, $W(189) = 0.554$, $p < 0.001$, and the ‘with distractor’ condition, $W(189) = 0.577$, $p < 0.001$.

Given that all variables significantly deviated from normality, non-parametric tests (Friedman test and subsequent post hoc tests) were conducted as was done previously. The results of the Freidman test indicated that there was a statistically significant difference in these psycholinguistic properties across the conditions, $\chi^2(5, N = 189) = 429.859$, $p < 0.001$.

Post-hoc analysis using the Wilcoxon signed-rank tests was conducted to examine the pairwise differences between the ‘without distractor’ and ‘with distractor’ conditions for each psycholinguistic property. The Wilcoxon signed-rank test indicated that imagery scores were significantly higher in the ‘without distractor’ condition ($M = 4.5$, $SD = 1.48$) than in the ‘with distractor’ condition ($M = 3.69$, $SD = 1.27$), $Z = -4.84$, $p < 0.001$. Similarly, concreteness scores were significantly higher in the ‘without distractor’ condition ($M = 4.67$, $SD = 1.52$) compared to the ‘with distractor’ condition ($M = 3.76$, $SD = 1.08$), $Z = -5.31$, $p < 0.001$. However, there was no significant difference in word frequency between the ‘without distractor’ ($M = 61.99$, $SD = 97.38$) and ‘with distractor’ conditions ($M = 78.87$, $SD = 175.79$), $Z = -1.35$, $p = 0.175$.

Furthermore, the psycholinguistic properties of the words used across six different recall conditions (Increasing, Decreasing, and Equal ISI recall without distractor as well as Increasing, Decreasing, and Equal ISI recall with distractor) were analysed to ensure comparability across conditions. The words were analysed for the variables of Imagery, Concreteness, and Word Frequency. The Shapiro–Wilk test was used to assess the normality of the distributions for each condition within each variable. For Imagery, the results indicated significant deviations from normality in most conditions: Increasing ISI recall without distractor, $W(63) = 0.916$, $p < .001$; Decreasing ISI recall without distractor, $W(63) = 0.927$, $p = .001$; Equal ISI recall without distractor, $W(63) = 0.931$, $p = .002$; and Increasing ISI recall with distractor, $W(63) = 0.951$, $p = .014$. Decreasing ISI recall with distractor, $W(63) = 0.972$, $p = .168$, and Equal ISI recall with distractor, $W(63) = 0.965$, $p = .073$, did not show significant deviations, suggesting approximate normality for these two conditions. Similarly, for Concreteness, the Shapiro–Wilk test showed significant deviations from normality across all six conditions: Increasing ISI recall without distractor, $W(63) = 0.903$, $p < .001$; Decreasing ISI recall without distractor, $W(63) = 0.908$, $p < .001$; Equal ISI recall without distractor, $W(63) = 0.891$, $p < .001$; Increasing ISI recall with distractor, $W(63) = 0.904$, $p < .001$; Decreasing ISI recall with distractor, $W(63) = 0.939$, $p = .004$; and Equal ISI recall with distractor, $W(63)$

= 0.919, $p < .001$. For Word Frequency, the Shapiro–Wilk test also indicated significant deviations from normality across all conditions: Increasing ISI recall without distractor, $W(63) = 0.556$, $p < .001$; Decreasing ISI recall without distractor, $W(63) = 0.670$, $p < .001$; Equal ISI recall without distractor, $W(63) = 0.593$, $p < .001$; Increasing ISI recall with distractor, $W(63) = 0.476$, $p < .001$; Decreasing ISI recall with distractor, $W(63) = 0.643$, $p < .001$; and Equal ISI recall with distractor, $W(63) = 0.431$, $p < .001$. These results suggest that the distributions for Concreteness and Word Frequency deviated significantly from normality across all six recall conditions, while Imagery scores showed approximate normality in some conditions but not others.

Given that all variables significantly deviated from normality, non-parametric tests were conducted. Separate Friedman tests were performed to examine differences across the six conditions for Imagery, Concreteness, and Word Frequency. For Imagery, the Friedman test revealed a statistically significant difference across the six conditions, $\chi^2(5) = 49.959$, $p < .001$. Similarly, for Concreteness, a statistically significant difference was also found, $\chi^2(5) = 61.211$, $p < .001$. However, for Word Frequency, the Friedman test indicated no significant difference across conditions, $\chi^2(5) = 7.577$, $p = .181$. These results suggest that the distributions of Imagery and Concreteness scores significantly differed across conditions, whereas Word Frequency remained comparable.

Wilcoxon Signed Ranks Tests were conducted to compare Imagery scores between the six conditions. Results indicated that imagery scores for the Increasing ISI with distractor condition were significantly lower than the scores for the Increasing ISI without distractor condition, $Z = -3.765$, $p < .001$. Similarly, the imagery scores for the Decreasing ISI with distractor condition were significantly lower than the scores for the Decreasing ISI without distractor condition, $Z = -4.958$, $p < .001$, and the imagery scores for the Equal ISI with distractor condition were significantly lower than the scores for the Equal ISI without distractor condition, $Z = -3.738$, $p < .001$.

However, no significant differences were found between imagery scores for Decreasing ISI and Increasing ISI without distractor, $Z = -0.236$, $p = .814$, or between Equal ISI without distractor and Increasing ISI without distractor, $Z = -0.722$, $p = .471$. Comparisons between imagery scores for Decreasing ISI and Increasing ISI with distractor, $Z = -1.733$, $p = .083$, and between the imagery scores for Equal ISI without and with distractor, $Z = -0.396$, $p = .692$, also revealed no significant differences. Results also showed no significant differences between the Decreasing ISI without distractor and Equal ISI without distractor conditions, $Z = -0.729$, $p = .466$, and no significant differences between the Decreasing ISI with distractor and Equal ISI with distractor conditions, $Z = -1.568$, $p = .117$. These findings suggest that some comparisons, particularly those involving Increasing, Decreasing, and Equal ISI with distractor conditions relative to their matched Increasing, Decreasing, and Equal ISI without distractor conditions, showed significant reductions in imagery ratings, while others did not differ significantly. This has already been demonstrated by the results obtained when comparing the psycholinguistic properties between the without distractor and with distractor conditions.

Wilcoxon Signed Ranks Tests were also conducted to compare Concreteness scores between the six conditions. Results indicated that Concreteness scores for the Increasing ISI with distractor condition were significantly lower than the scores for the Increasing ISI without distractor condition, $Z = -4.166$, $p < .001$. Similarly, the Concreteness scores for the Decreasing ISI with distractor condition were significantly lower than the scores for the Decreasing ISI without distractor condition, $Z = -5.259$, $p < .001$, and the Concreteness scores for the Equal

ISI with distractor condition were significantly lower than the scores for the Equal ISI without distractor condition, Z = -3.352, p < .001.

However, no significant differences were found between Concreteness scores for Decreasing ISI and Increasing ISI without distractor, Z = -0.074, p = .941, or between Equal ISI without distractor and Increasing ISI without distractor, Z = -1.653, p = .098. Comparisons between Concreteness scores for Decreasing ISI and Increasing ISI with distractor, Z = -1.911, p = .056, and between the Concreteness scores for Equal ISI without and with distractor, Z = -0.954, p = .340, also revealed no significant differences. Results also showed no significant differences between the Decreasing ISI without distractor and Equal ISI without distractor conditions, Z = -1.688, p = .091, and no significant differences between the Decreasing ISI with distractor and Equal ISI with distractor conditions, Z = -0.996, p = .319. These findings suggest that, like for Imagery, significant reductions in Concreteness ratings were found for the with distractor conditions relative to their matched without distractor conditions, while other comparisons did not differ significantly. We already know this from the results obtained when comparing the psycholinguistic properties between the without distractor and with distractor conditions.

Wilcoxon Signed Ranks Tests were additionally conducted to compare Word Frequency scores between the six conditions. Results indicated that no significant differences were found between the Increasing ISI with distractor and Increasing ISI without distractor conditions, Z = -0.705, p = .481. Similarly, no significant differences were found between Decreasing ISI with distractor and Decreasing ISI without distractor, Z = -0.154, p = .877, or between Equal ISI with distractor and Equal ISI without distractor, Z = -0.880, p = .379.

Additionally, comparisons between Decreasing ISI and Increasing ISI without distractor, Z = -1.437, p = .151, between Equal ISI without distractor and Increasing ISI without distractor, Z = -2.096, p = .036, and between Decreasing ISI and Increasing ISI with distractor, Z = -0.593, p = .553, also showed no significant differences. Furthermore, comparisons between Equal ISI without and with distractor, Z = -2.181, p = .029, did not reveal significant differences. No significant differences were seen between Decreasing ISI without distractor and Equal ISI without distractor conditions, Z = -1.210, p = .226, and no significant differences between Decreasing ISI with distractor and Equal ISI with distractor conditions, Z = -1.052, p = .293. These findings suggest that, unlike Imagery and Concreteness, Word Frequency scores remained comparable across the six recall conditions.

Analysis was also completed of the psycholinguistic properties of the words presented at each serial position to ensure comparability across the list. Words were analysed for the variables of Imagery, Concreteness, and Word Frequency. The Shapiro–Wilk test was used to assess the normality of the distributions at each serial position within each variable. For Imagery, the results indicated significant deviations from normality at several positions: Position 2, W(54) = 0.949, p = .022; Position 4, W(54) = 0.941, p = .010; and Position 5, W(54) = 0.948, p = .020. Positions 1, 3, 6, and 7 did not show significant deviations from normality (ps > .05), suggesting approximate normality at these positions. Similarly, for Concreteness, the Shapiro–Wilk test indicated significant deviations from normality across most positions: Position 1, W(54) = 0.945, p = .016; Position 2, W(54) = 0.881, p < .001; Position 3, W(54) = 0.937, p = .007; Position 4, W(54) = 0.898, p < .001; Position 5, W(54) = 0.921, p = .002; Position 6, W(54) = 0.906, p < .001; and Position 7, W(54) = 0.895, p < .001. For Word Frequency, the Shapiro–Wilk test indicated significant deviations from normality at all positions: Position 1, W(54) = 0.523, p < .001; Position 2, W(54) = 0.722, p < .001; Position

3, W(54) = 0.502, $p < .001$; Position 4, W(54) = 0.320, $p < .001$; Position 5, W(54) = 0.687, $p < .001$; Position 6, W(54) = 0.575, $p < .001$; and Position 7, W(54) = 0.446, $p < .001$. These results suggest that the distributions for Concreteness and Word Frequency deviated significantly from normality across almost all serial positions, while Imagery scores showed approximate normality at some positions but significant deviations at others.

Given that most variables significantly deviated from normality, non-parametric tests were conducted. Separate Friedman tests were performed to examine differences across the seven word positions for Imagery, Concreteness, and Word Frequency. For Imagery, the Friedman test did not show a statistically significant difference across the seven positions, $\chi^2(6) = 8.822$, $p = .184$. Similarly, for Concreteness, no statistically significant difference was found, $\chi^2(6) = 6.259$, $p = .395$. Again, for Word Frequency, the Friedman test indicated no significant difference across positions, $\chi^2(6) = 2.960$, $p = .814$. These results suggest that Imagery, Concreteness, and Word Frequency remained relatively consistent across the seven word positions.

3.3.2 Proactive interference

Before we go on to analysis of the complete data, it may be advisable to examine the impact of proactive interference. It may be possible to strengthen the conclusions drawn about PI later on in the study by examining performance ONLY on list 1 of this experiment (before PI has a chance to build up) and drawing some preliminary conclusions. Therefore, only set 1 of all three ISI conditions is examined here graphically.

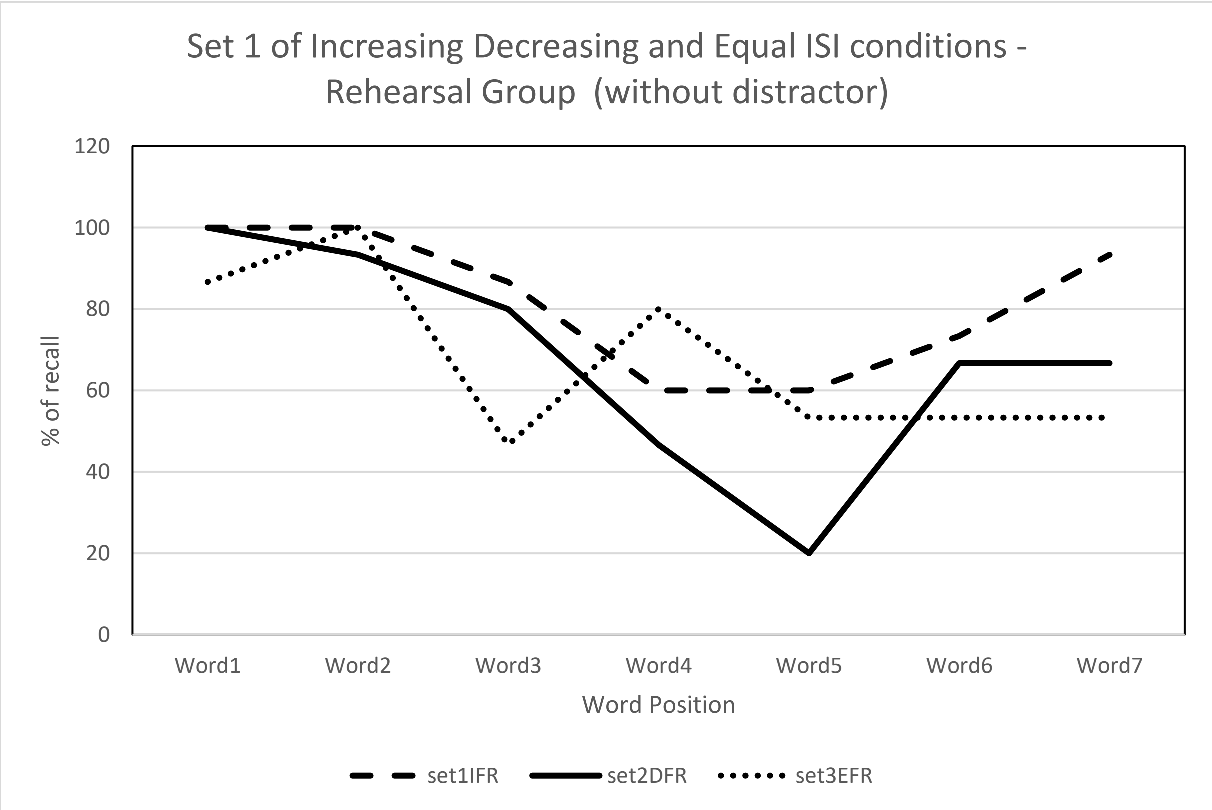

Figure 3.2 Set 1 of Increasing, Decreasing and Irregular ISI conditions as a function of percentage recalled in the rehearsal group without distractor.

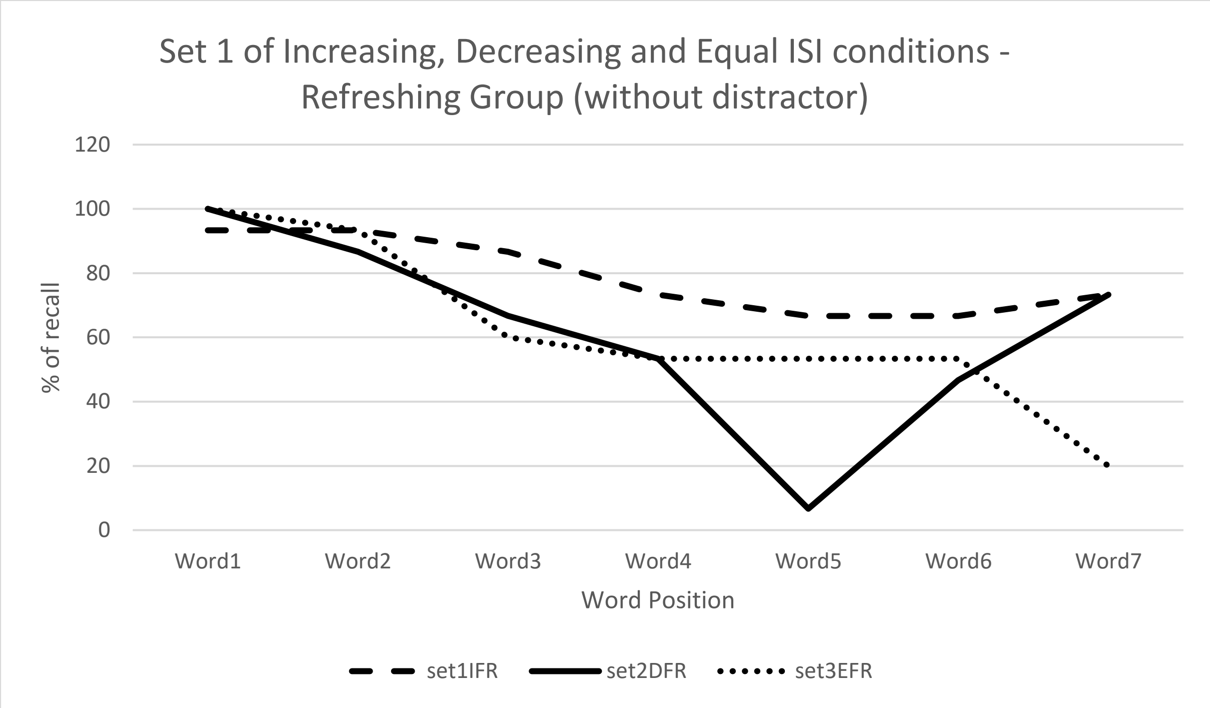

Figure 3.3 Set 1 of Increasing, Decreasing and Irregular ISI conditions as a function of percentage recalled in the refreshing group without distractor.

As can be seen in Figure 3.2 and 3.3, there is a slight advantage of the first set (increasing free recall) in overall percentage of items recalled in both groups. However, the trend of the increasing free recall condition is very variable. Even though, the overall percentage of items recalled is slightly lower in the decreasing free recall condition, the trend still shows the impact of temporal isolation along with some recency effects as seen by the increase in recall of word 6 and word 7. This will be examined further when analysing the full dataset. However, given what we know regarding the impact of proactive interference, and the results of the present experiment, it may be beneficial to explore reducing the proactive interference if possible.

Results of word recall across conditions

Items were scored as correct irrespective of the position within the list of nine items. Results were calculated as the number of times each serial position was recalled in a given trial by each participant. In other words, frequency of recall was calculated for each serial position. A Temporal Isolation Variable (TIV) was calculated and again, the scores for the first and last item (here, the words START and STOP) were omitted. Hence, the abscissa for the figures is 1-5 items.

A repeated-measures ANOVA with factors of item position (five levels), item lag condition (three levels), and distractor condition (two levels) was conducted for the Rehearsal group. There were significant main effects of item position, $F(4, 56) = 5.46$, $MSe = 2.72$, $p < .001$, $\eta p^2 = .28$, and distractor condition, $F(1, 14) = 106.25$, $MSe = 3.71$, $p < .001$, $\eta p^2 = .88$, whereas the main effect of item lag condition was not significant, $F(2, 28) = 0.47$, $MSe = 3.44$, $p = .63$. Significant interactions were observed between item position and item lag condition, $F(8, 112) = 4.56$, $MSe = 1.90$, $p < .001$, $\eta p^2 = .24$, and between item position and distractor condition, $F(4, 56) = 10.74$, $MSe = 1.60$, $p < .001$, $\eta p^2 = .43$. The interaction between distractor condition and item lag condition was not significant, $F(2, 28) = 3.31$, $MSe = 1.57$, $p = .05$. However, there was a significant three-way interaction among item position, item lag condition, and distractor condition, $F(8, 112) = 3.80$, $MSe = 1.90$, $p < .001$, $\eta p^2 = .21$.

Post hoc Bonferroni-corrected comparisons revealed that word 2 ($M = 6.14$, $SD = 0.35$) was recalled significantly more often than word 4 ($M = 4.46$, $SD = 0.30$), $t(14) = 3.51$, $p = .004$, and word 5 ($M = 4.32$, $SD = 0.19$), $t(14) = 3.91$, $p = .002$. Recall performance was also significantly better in trials without a distractor ($M = 5.54$, $SD = 0.21$) compared to trials with a distractor ($M = 4.18$, $SD = 0.24$), $t(14) = 10.31$, $p < .001$. Pairwise comparisons between the Increasing ISI, Decreasing ISI, and Equal ISI conditions revealed no significant differences ($p > .05$), suggesting that item position and the presence or absence of articulatory rehearsal had stronger effects on recall than differences in inter-stimulus intervals.

Similarly, a repeated-measures ANOVA with Greenhouse–Geisser correction was conducted for the Refreshing group. There were significant main effects of item position, $F(1.15, 21.2) = 11.01$, $MSe = 15.7$, $p < .001$, $\eta p^2 = .44$, item lag condition, $F(2, 28) = 7.37$, $MSe = 1.64$, $p < .001$, $\eta p^2 = .35$, and distractor condition, $F(1, 14) = 37.24$, $MSe = 5.55$, $p < .001$, $\eta p^2 = .73$. Significant interactions were found between item position and item lag condition, $F(8, 112) = 7.94$, $MSe = 2.24$, $p < .001$, $\eta p^2 = .36$, and between item position and distractor condition, $F(4, 56) = 6.46$, $MSe = 1.76$, $p < .001$, $\eta p^2 = .32$, although the interaction between distractor condition and item lag condition was not significant, $F(2, 28) = 1.90$, $MSe = 2.37$, $p = .16$, and the three-way interaction was also non-significant, $F(8, 112) = 1.40$, $MSe = 2.04$, $p = .20$.

Post hoc Bonferroni-corrected comparisons indicated that word 2 ($M = 6.14$, $SD = 0.35$) was recalled significantly more than word 3 ($M = 5.30$, $SD = 0.30$), $t(14) = 4.15$, $p = .001$; word 4 ($M = 4.47$, $SD = 0.31$), $t(14) = 5.82$, $p < .001$; word 5 ($M = 4.32$, $SD = 0.19$), $t(14) = 6.34$, $p < .001$; and word 6 ($M = 4.07$, $SD = 0.34$), $t(14) = 6.91$, $p < .001$. In addition, trials without a distractor ($M = 5.54$, $SD = 0.21$) resulted in significantly better recall compared to trials with a distractor ($M = 4.19$, $SD = 0.24$), $t(14) = 8.72$, $p < .001$. Pairwise comparisons showed that recall was significantly higher in the Equal ISI condition ($M = 5.15$, $SD = 0.21$) compared to the Decreasing ISI condition ($M = 4.85$, $SD = 0.20$), $t(14) = 2.31$, $p = .037$, although no significant difference was found between the Increasing ISI and Decreasing ISI conditions, $t(14) = 1.89$, $p = .079$.

Paired-samples t-tests further revealed that, for the Rehearsal group, recall was significantly higher in the Decreasing ISI ($M = 29.5$, $SD = 1.57$) and Increasing ISI ($M = 29.3$, $SD = 1.72$) conditions without a distractor compared to the Equal ISI condition ($M = 27.8$, $SD = 1.90$). Specifically, the Decreasing ISI vs Equal ISI comparison was significant, $t(14) = 2.75$, $p = .016$, as was the Increasing ISI vs Equal ISI comparison, $t(14) = 2.43$, $p = .029$. Recall was significantly higher across all item lag conditions when no distractor was present.

Similarly, for the Refreshing group, recall was significantly lower in the Decreasing ISI condition ($M = 25.5$, $SD = 1.33$) compared to both the Increasing ISI ($M = 28.6$, $SD = 1.20$) and the Equal ISI ($M = 29.0$, $SD = 1.24$) conditions. Paired comparisons confirmed that recall was significantly better in the Increasing ISI compared to the Decreasing ISI condition, $t(14) = 2.48$, $p = .027$, and significantly better in the Equal ISI compared to the Decreasing ISI condition, $t(14) = -3.12$, $p = .007$. As with the Rehearsal group, recall was consistently higher across all item lag conditions when no distractor was present.

Finally, an independent-samples t-test comparing the Rehearsal and Refreshing groups revealed no significant difference in overall recall performance, $t(28) = 0.31$, $p = .759$, suggesting that controlling articulatory rehearsal versus attentional refreshing led to similar outcomes in memory performance

Similar to Experiment 1, differences were observed in performance for the increasing and decreasing ISI conditions with the mean recall for decreasing ISI being somewhat lower. However, as shown in Fig. 3.5 in the decreasing ISI condition, in both groups Rehearsal and Refreshing, there appear to be benefits of temporal isolation, with higher recall (6-8) of items that have higher TIV – items 2 and 3. Recall performance also appears lower (3-5) for more temporally crowded items (items 5 and 6). First a broad description of performance trends across the spacing and task conditions is provided.

Noteworthy is that articulatory suppression significantly reduces performance: compare ‘with’ and ‘without’ distractor performance for the Rehearsal group in Fig. 3.5. Note too that the *decreasing* ISI performance profile across items is a somewhat flatter one with the frequency of recall ranging between 3.5 and 4.7. It is also observed that recall is only slightly higher for item 2 (first item for recall) which has the highest TIV. The *increasing* ISI performance profile also tells a similar story of the benefits of temporal isolation with lower recall for item 2 with lowest TIV and higher recall for item 6 the highest TIV.

Similarly, in the Refreshing group, performance was reduced significantly compared to a condition without a distractor task (as shown in Fig, 3.5 and Fig.3.8). The *decreasing* ISI performance profile is not flat, although benefits of a higher TIV are apparent, with highest recall performance (~ 6) for item 2; and lowest recall performance for item 6 with the lowest TIV (~ 3). The higher TIV for items 3 and 4 in *decreasing* ISI also helps in improving performance although a typical serial position curve would show dips in the middle items. Here, as we can see in *decreasing* ISI the curve is trending upwards as the TIV increases.

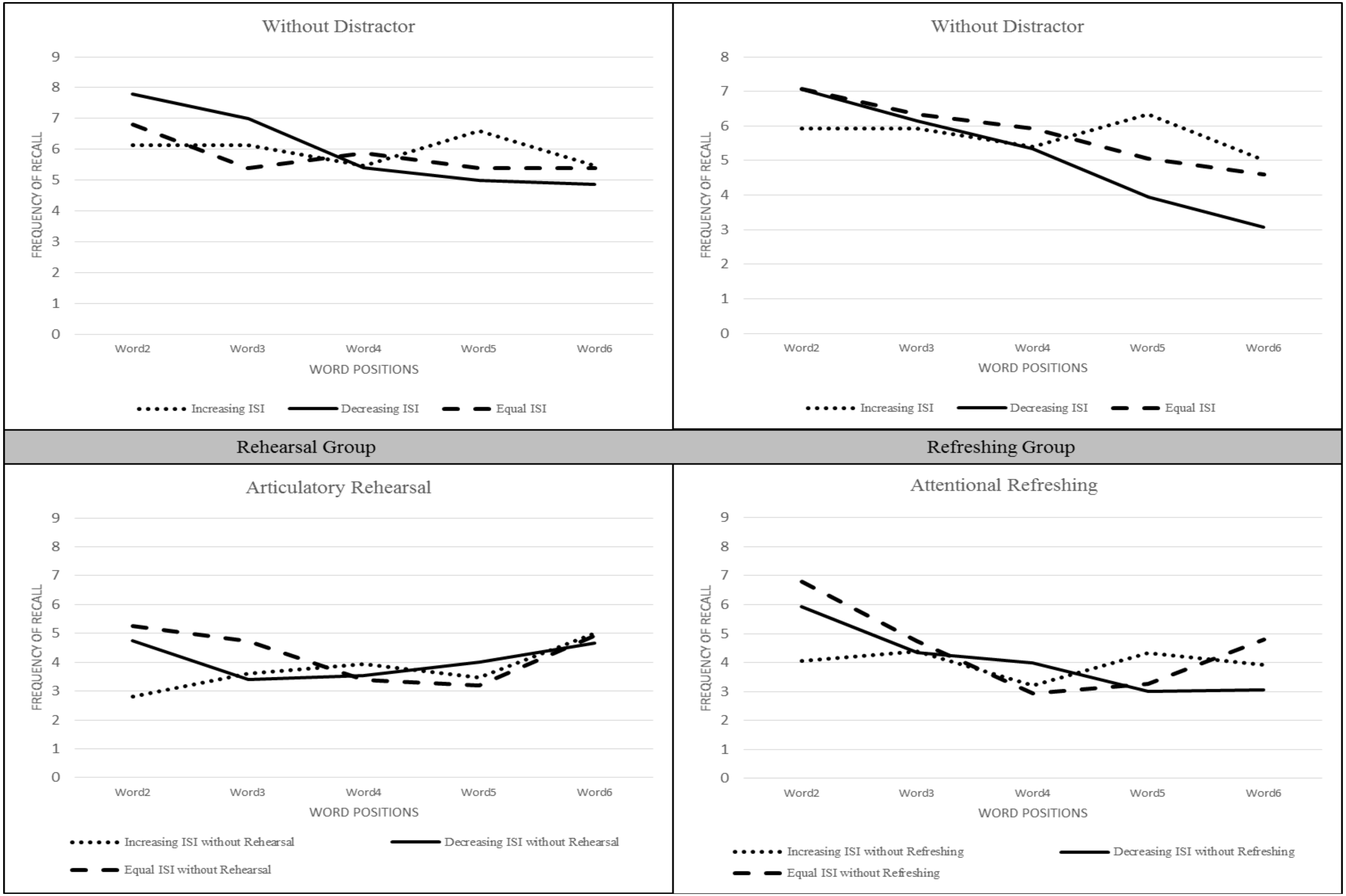

Figure 3.4 Performance in Increasing, Decreasing and Equal ISI conditions (with and without distractor) for different word positions Rehearsal group and Refreshing group

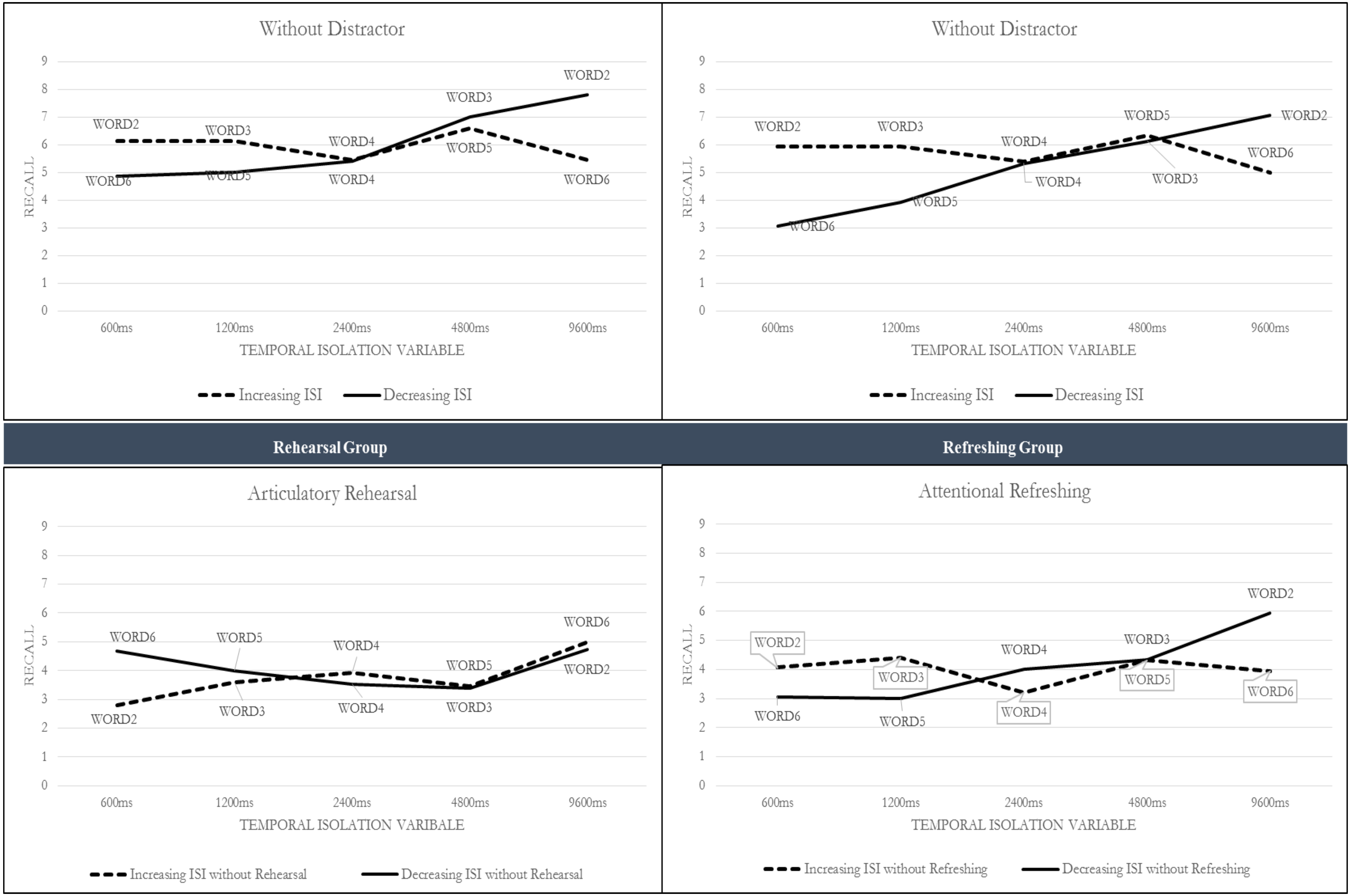

Figure 3.5 Performance in Increasing ISI condition and Decreasing ISI condition (with and without distractor) arranged along TIV Scale for Rehearsal group and Refreshing group

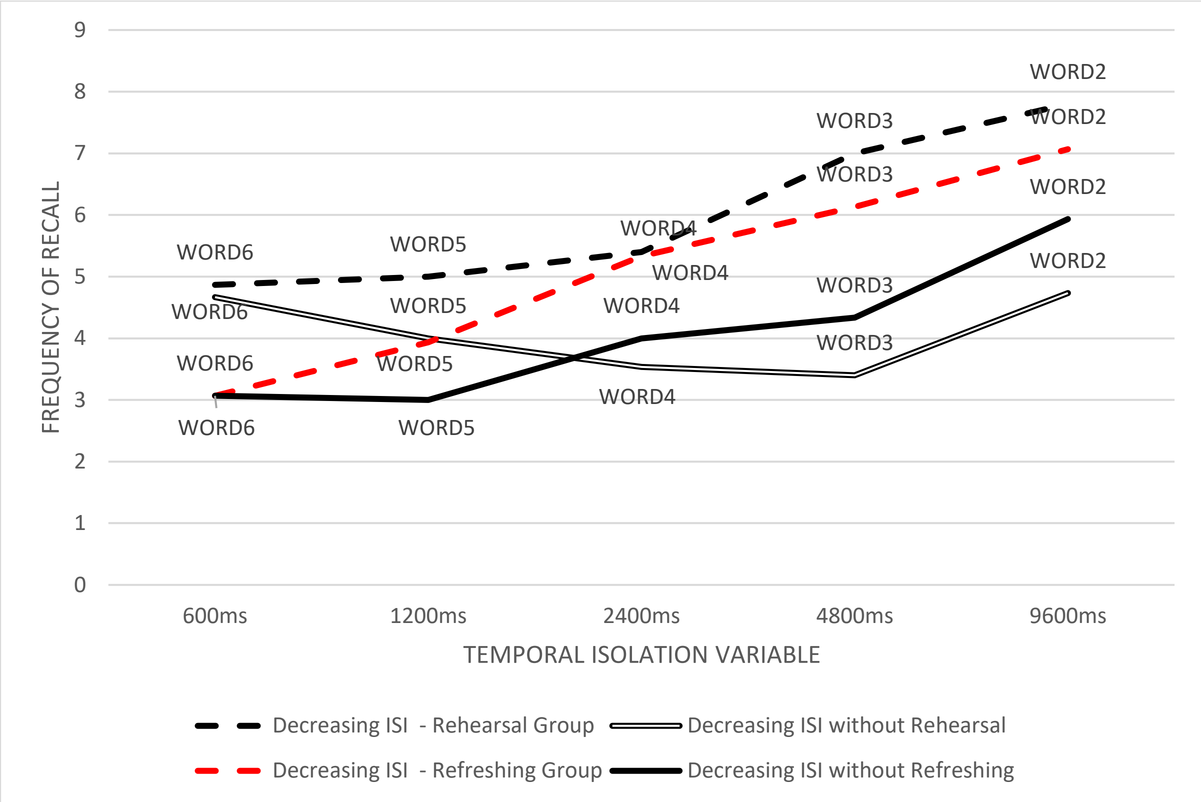

Figure 3.6 Performance in Decreasing ISI condition arranged along TIV scale for Rehearsal Group and Refreshing group (with and without distractor)

This indicates that, apart from serial position, attentional refreshing and articulatory rehearsal having an influence on performance, which was known to be true from previous research (*see* Introduction), the spacing or the schedule of presentation of information has an important impact on performance on its own but also interacts with the other factors to produce a significant effect on recall. For instance, in the Rehearsal group, we see a significant influence of the interaction between the temporal spacing of an item and the position of the item within the list. Similarly, the position of the item within the list, coupled with whether there was a distractor or not had a significant effect on the recall of that item, not only in the Rehearsal group but also in the Refreshing group. Additionally, in the Refreshing group, a similar picture emerged. However, a significant three-way interaction between all the three factors was not seen here as was seen in the Rehearsal group.

3.3.1 Temporal Contraction

As explained in Experiment 1, the decreasing ISI condition is referred to as temporal contraction. When the serial position curve simulated from the SIMPLE model is compared to the serial position curve obtained in the current experiment, it can be seen that the curves are similar and the curve in the present experiment is somewhat flatter.

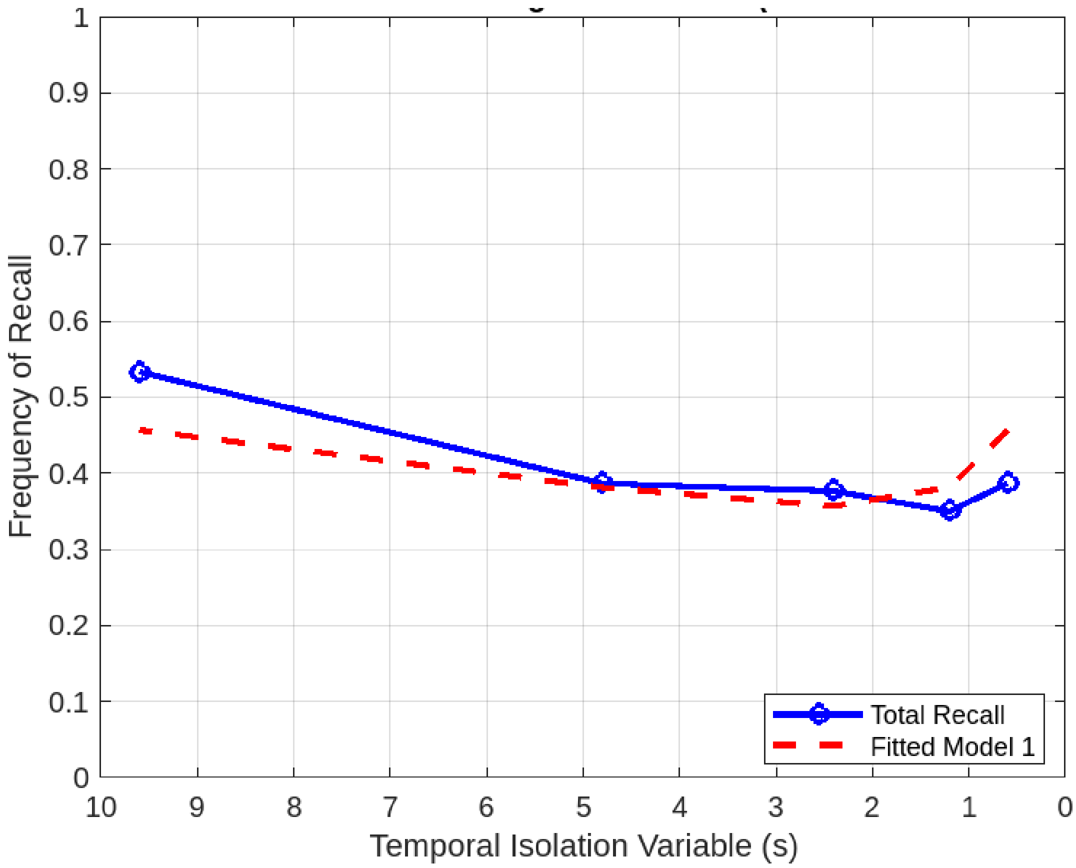

Figure 3.7 Temporal Contraction- Total Recall Data Fit to SIMPLE Model for Decreasing ISI condition (not controlled for refreshing and rehearsal)

The aim is to examine the goodness of fit to the SIMPLE model in predicting recall performance under a Decreasing ISI condition. In this condition, the time between item presentations was progressively reduced, potentially affecting the temporal distinctiveness of items and their recall likelihood. The dataset analysed was the total recall for both rehearsal and refreshing groups without distractor, both consisting of recall frequencies measured across seven Temporal Isolation Variables (TIV) ranging from 9.6 seconds to 0.15 seconds. The ISI was systematically decreased, affecting the TIV and expected recall outcomes. The SIMPLE model was fitted to the dataset with initial parameter estimates set at c = 0.5, slope = 20, and thresh = 0.2. Model parameters were optimized using the fminsearch function in MATLAB, which minimizes the sum of squared differences between observed and predicted recall probabilities. Figure 3.7 illustrates the observed recall frequencies and their respective SIMPLE model predictions. The SIMPLE model provided a moderate fit to the dataset, with R^2 value of 0.52752 for the total recall data for both rehearsal and refreshing groups without distractor. The value indicates that the model explains approximately 52.75% of the variance in the dataset. Future research could explore modifications to the SIMPLE model that incorporate variable encoding rates or adaptive threshold mechanisms to better capture these dynamics. The

SIMPLE model demonstrated a good fit for the total recall in both groups in the decreasing ISI condition.

The parameter settings used for fitting the SIMPLE model to the total recall data for the rehearsal and refreshing groups without distractor under the Decreasing ISI condition provide important insights into the cognitive mechanisms underlying recall performance. The distinctiveness parameter (c) was initialized at 0.5, reflecting a moderate sensitivity to differences in temporal separation between items. Psychologically, this suggests that participants were assumed to be moderately responsive to changes in temporal distinctiveness, sensitive enough to distinguish temporally isolated items, but not at a maximum level that would exaggerate small differences in item spacing. As the ISI progressively decreased, temporal crowding likely intensified, making it harder to maintain distinct temporal representations toward the end of the list. A moderate c value captures this gradual compression of psychological time, consistent with participants' increasing difficulty in differentiating items presented with shorter intervals. The slope parameter, initialized at 20, determined the steepness of the relationship between distinctiveness and recall probability. A relatively steep slope indicates that once an item's distinctiveness exceeded a critical point, participants were assumed to transition sharply from low to high recall probability, suggesting a relatively categorical recall process rather than a gradual or probabilistic one. This is consistent with psychological theories proposing that when retrieval cues (such as distinctiveness) are strong enough, recall decisions are made decisively rather than slowly accumulating evidence. The threshold parameter (thresh), initialized at 0.2, reflected the minimum level of distinctiveness required for an item to be recalled. A relatively low threshold suggests a more liberal retrieval criterion, whereby participants would attempt to recall items even when they were only moderately distinctive. In the Decreasing ISI condition, where item spacing systematically compressed, such a low threshold would have been adaptive, allowing participants to retrieve items even under less-than-optimal distinctiveness conditions.

As seen in the previous experiment, the parameter settings and the model's moderate fit ($R^2 = 0.52752$) suggest that while temporal distinctiveness plays a key role in driving recall performance, additional cognitive processes likely contributed under conditions of compressed temporal spacing. Participants may have supplemented distinctiveness-based retrieval with strategic encoding, increased attentional focus on early list items, or adaptive threshold adjustments in response to rapid presentation rates.

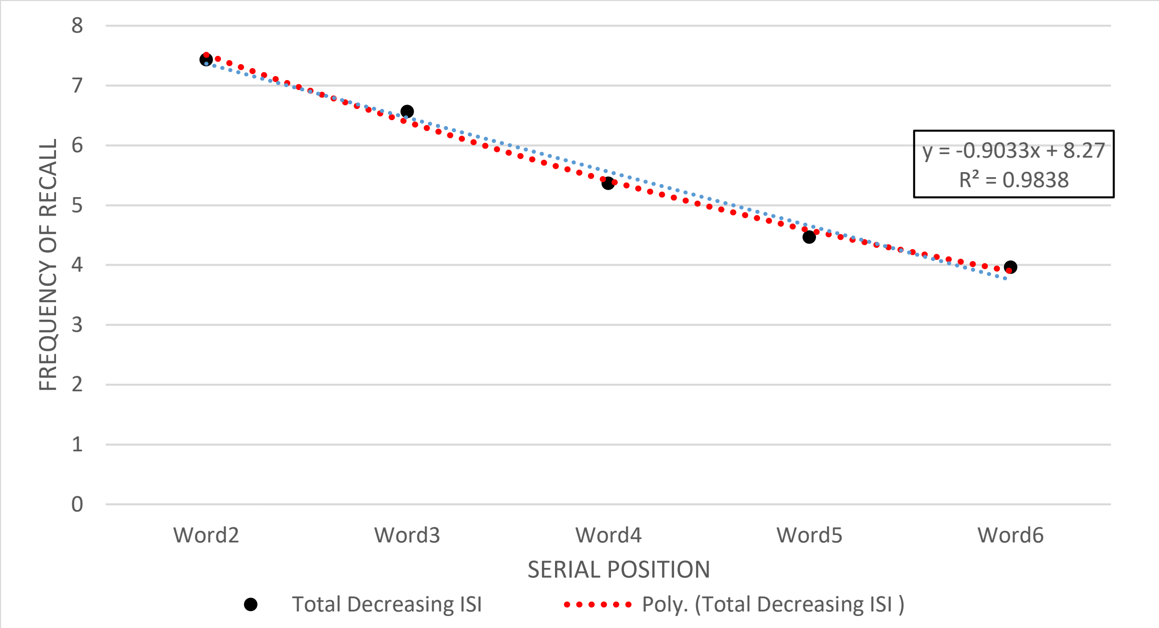

Figure 3.2 Decreasing ISI condition (not controlled for refreshing and rehearsal) and polynomial trendline in both groups (Temporal Contraction)

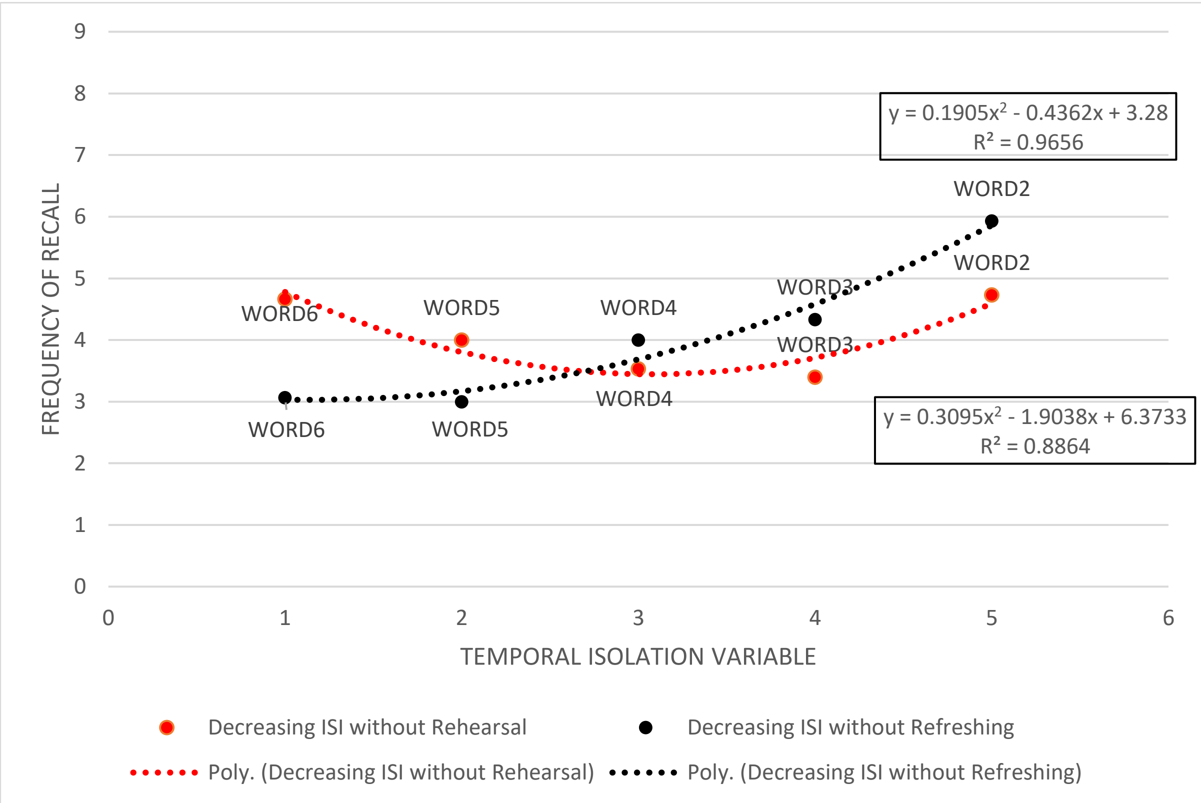

Figure 3.3 Decreasing ISI condition (controlled for refreshing and rehearsal) and polynomial trendline.

The recall for the decreasing ISI condition, controlled for refreshing is also easily explained by the SIMPLE model in that the effect of temporal isolation is seen clearly. However, it is worth noting that the recall for decreasing ISI condition, controlled for rehearsal is akin to the well-known dipped U-shaped curve of serial position although the present curve is much flatter.

3.4 Discussion

As the stimuli were not randomly selected, the psycholinguistic properties of the verbal stimuli selected were analysed retrospectively as in Experiment 1. The analysis of psycholinguistic properties in the present experiment, including Imagery, Concreteness, and Word Frequency, across the ISI conditions indicated no significant differences in these variables between the Increasing, Decreasing, and Equal ISI conditions. This finding suggests that the observed effects on recall performance are not attributable to differences in these psycholinguistic features. Despite significant deviations from normality in the distribution of these properties, non-parametric analyses showed that Imagery, Concreteness, and Word Frequency did not systematically vary across the ISI conditions, supporting the notion that these factors were controlled for adequately.

The potential impact of proactive interference (PI) could be observed graphically, when examining performance on list 1 of each ISI condition. There is a slight advantage of the first set (increasing free recall) in overall percentage of items recalled in both groups. However, the trend of the increasing free recall condition is very variable. Even though, the overall percentage of items recalled is slightly lower in the decreasing free recall condition, the trend still shows the impact of temporal isolation along with some recency effects as seen by the increase in recall of word 6 and word 7. This will be examined further when analysing the full dataset. However, given what we know regarding the impact of proactive interference, and the results of the present experiment, it may be beneficial to explore reducing the proactive interference if possible.

The positive effects on recall for items with high TIV seen in this experiment across all ISI conditions is consistent with not only our own previous study but many others. Although articulatory rehearsal and attentional refreshing have reduced performance significantly (corroborated by many studies e.g. (Camos et al., 2011; Camos et al., 2009; Morra, 2015; Bhatarah et al., 2009), the serial position curve has not shown much of a change from our previous experiment for both increasing and decreasing schedules of presentation. This is consistent with the view that the effects of both articulatory rehearsal and attentional refreshing in memory, although significant, is independent of the effects of serial position or indeed, temporal isolation.

An early study by Welte and Laughery (1971) suggested that when an increasing schedule was presented, there was an overall increase in the recall of all the earlier items as when the longer ISI occurs later in the sequence, participants are able to rehearse more of the items better. This seems to have been replicated in this experiment as well since higher rates of recall is seen for the first few items in the increasing schedule without any distractor than for the trials that controlled for articulatory rehearsal and attentional refreshing. They also said that decreasing schedule does not allow for much rehearsal of the first few items as their results showed that performance on the first few items is lower than the last few items. However, the present study has obtained inconsistent results. The performance for the first few items with the higher TIV has been consistently higher than the others in a decreasing schedule, with or without adding distractors to control for articulatory rehearsal and attentional refreshing. This provides further evidence that recall is not only dependent on rehearsal and refreshing strategies but also how temporally crowded the items are and what is more, their effects on memory are completely independent of each other which is consistent with many others (Schendel and

Palmer, 2007; Ritchie et al., 2015; Romani et al., 2005; Camos et al., 2011; Trapp et al., 2014; Raye et al., 2007).

The flatter nature of the serial position curve seen in the decreasing schedule in trials that control for articulatory rehearsal is a really encouraging result within the context of the present postulation that decreasing ISI schedule will lead to (approximately) equal probability of recall for all the items in the list and therefore, will render the serial position curve flat. Even though performance has decreased, all serial positions are recalled equally. This means that if we insert adequate spacing between the to-be-remembered items, then it can lead to reduction in primacy and recency effect and performance will be dependent on the temporal isolation of the item. But then again, it is not only dependent on the temporal isolation, but on the correct (logarithmic) compressive scheduling of the items. We needed to interpret these results with caution as the sample size was quite low and therefore, we decided to conduct a two-trial experiment, with a higher sample size.

Chapter 4 - The question of proactive interference

4.1 Introduction to Experiment 3

As reported in Chapters 2 and 3, tests were made of the influences and possible advantages of a particular temporal schedule of presentation of verbal memoranda on their subsequent recall. While there was some preliminary evidence for the decreasing ISI temporal schedule leading to enhanced recall in Experiment 1, it was apparent that there could be a number of confounding factors, most notable being a possible role for verbal rehearsal or attentional refreshing of the memoranda. Consequently, the second experiment focussed on replicating the results of the preceding experiment whilst trying to minimise other factors that could be contributing to item maintenance like rehearsal and refreshing. The present experiment is an attempt to confront another such confounding factor – proactive interference. Proactive interference is the well-established phenomenon where prior learning interferes with new learning. This means, therefore, that in the present series of experiments (which have a large number of trials), items in the previous trials could interfere with learning the items in future trials. Hence, it might seem sensible to reduce the number of trials to combat proactive interference; unfortunately, a relatively large number of trials is needed to get good normative data for a small but reasonably sized sample in an experiment. A different solution would be to increase the sample size rather than the trials. As explained in Introduction *(see section 1.2.2)* Baddeley and Scott (1971) conducted a single trial experiment (actually, participants experienced three discrete trials) in an attempt to eliminate the interference of stimuli from prior trials commonly observed in a multi trial experiment. The present experiment seeks to reduce the effects of proactive interference by using a similar approach.

The present experiment was methodologically similar to Experiment 2 but an important distinction was that it had only two trials per participant; thus greatly reducing the opportunity for proactive interference across trials (acknowledging influences within trials, although these effects will be reduced as well). One of the trials was presented with a *decreasing ISI* schedule and the other presented with an *equal ISI* schedule. Both trials introduced a control for articulatory rehearsal and for order of presentation: half the participants were exposed to the decreasing ISI trial first (Decreasing first group) and the other half being exposed to the equal ISI trial first (Equal first group). The increasing ISI schedule was dropped as a control condition, since, as explained previously, it was the decreasing ISI condition that was of interest in the present` study. However, the sample size was much higher to permit statistical evaluation in a very much reduced data set per participant. Also of interest here was the possible impact of the manipulation of inter-stimulus interval on recall. Note too that the realisation of the error made in the spacings of first and last items had not yet been made; for that reason, this temporal spacing error is still present, and performance was calculated by omitting items 1 and 8. The reader will, however, notice in the next chapter, that a satisfactory resolution to this problem has been reached. A further point to note is that in the previous experiments, performance was calculated as the number of times each serial position was recalled on a given trial by each participant; whereas, since this is a two-trial experiment, each participant will recall a particular serial position just once per spacing schedule. Calculating the percentage of participants that recalled for each serial position offers be a more reliable approach. The expectation remains the same as before: the decreasing ISI condition is predicted to demonstrate higher mean performance as well as a flatter trending serial position curve.

4.2 Methodology

4.2.1 Participants.

The 124 volunteers (males and females), aged between18 and 60, were recruited from the University of Leeds participant pool and through advertisements placed within the University Campus and assigned alternately to decreasing first group and equal first group (62 participants in each group). Decreasing first group had an average age of 19 years and the average age for equal first group was 19.4 years. They were native English Speakers, had normal/corrected to normal vision and had not been diagnosed with a neurological problem.

4.2.2 Stimuli.

The stimuli consisted of 16 health-related words taken from the Toronto Word Pool (Friendly et al., 1982) divided into two trials.

4.2.3 Materials and Design.

The experiment was designed on MS Powerpoint as there were only two trials and the programme was found to be sufficiently accurate in the timing of the presentation of stimuli (within tens of ms whereas the experimental manipulations are in the several hundred or thousands of ms). All stimuli were presented on the centre of the screen, in a 60- point Arial font for 1000ms. Participants were provided with a response sheet to record their responses. Each of the 2 trials consisted of 8 words each, not including START and STOP. The inter stimulus interval between individual words was manipulated to create only two item lag conditions - decreasing ISI with 12800, 6400, 3200, 1600, 800, 400, 200 ISIs from item 1 to 8; equal ISI with 2100ms ISIs from item 1 to 8. In each set, between START and STOP and the adjacent word there was an ISI of 100ms (*see* Fig. 4.1). Participants were divided into two groups. They were assigned to groups alternatively. E.g. Participant 1 in decreasing first group, Participant 2 in equal first group, Participant 3 in decreasing first group and so forth. Decreasing first group experienced the trial with decreasing ISIs first and; equal first group was presented with the equal ISI trial first. Thus, the presentation order was counterbalanced.

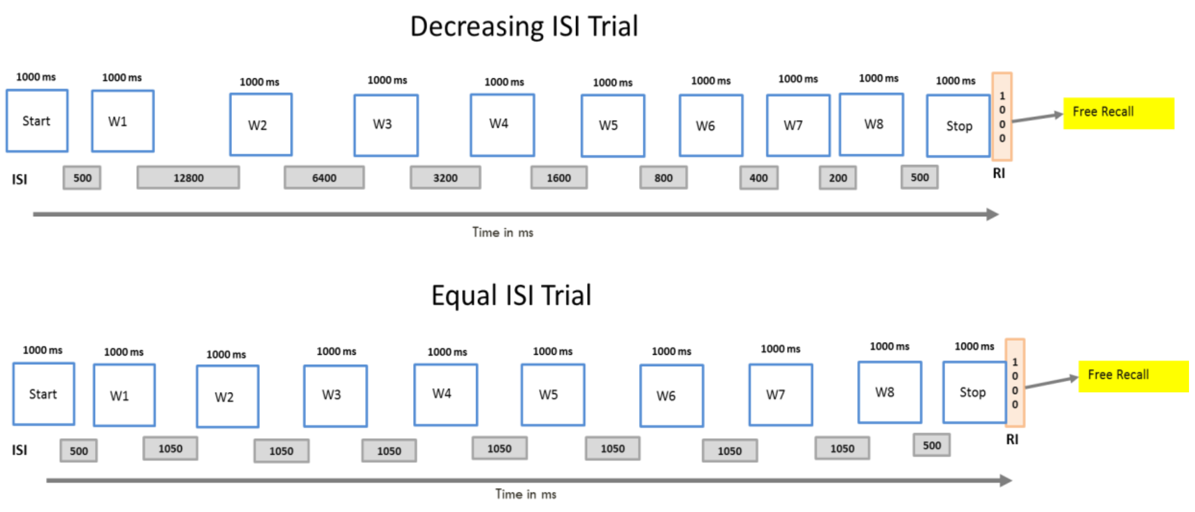

Figure 4.1 Inter Stimulus Intervals (ISI) in the two different item lag conditions (Decreasing ISI and Equal ISI)

4.2.4 Procedure.

Participants completed a simple computer administered verbal recall task consisting of 2 trials. However, unknown to the participants, the inter-stimulus interval (ISI) between individual words was manipulated to create two item lag conditions (decreasing ISI and equal ISI) with every participant being shown the decreasing ISI trial first. Each trial had 8 words (not including START and STOP) with either decreasing or equal ISI schedules. Both the trials controlled for articulatory rehearsal by requiring the participant to repeat the phrase '*coca cola'* between the presentations of the memoranda. It was explained that each set began with the word START and ended with the word STOP. They were instructed to carefully observe words that were shown on the screen and were informed that they will be asked to recall them in any order (free recall) at the end of each set when they were shown the picture of a pen on screen. They were further instructed not to write down these words during the presentation of the words on the screen. They were given as much time as required to write down the words they recalled on the response sheet provided. The experimental session lasted no longer than 5 minutes. Participants were tested individually with the experimenter present in the room.

4.3 Results

Psycholinguistic properties of the verbal stimuli

The psycholinguistic properties of the words used in three different ISI conditions (decreasing and equal ISI) were analysed to ensure comparability across conditions. A total of 16 words were used across two conditions (8 words each) and they were analysed for the variables of Imagery, Concreteness, and Word Frequency.

Normality tests were performed using the Shapiro-Wilk tests. Results indicated that Imagery in equal ISI ($p = .212$) and in decreasing ISI ($p = .649$), as well as Concreteness in equal ISI ($p = .118$), and decreasing ISI ($p = .777$) did not significantly deviate from normality. However, word frequency in equal ISI ($p < .001$) and in decreasing ISI ($p = .001$) were significantly non-normally distributed.

A Wilcoxon Signed Ranks Test was conducted to compare word frequency in equal and decreasing ISI as the data deviated from normality. The results revealed a Z-score of -0.280 ($p = .779$), indicating no significant difference between WFE and WFD.

A paired samples t-test was conducted to compare Imagery in equal ISI and decreasing ISI conditions and the mean difference was 0.48 ($SD = 2.31$), with a 95% confidence interval ranging from -1.46 to 2.41. The t-test yielded $t(7) = 0.582$, with a two-tailed significance of .579, suggesting no significant difference. For Concreteness, the mean difference between equal and decreasing ISI was 0.24 ($SD = 2.68$), with a 95% confidence interval from -2.00 to 2.48. The t-test resulted in $t(7) = 0.250$, with a two-tailed significance of .809, also indicating no significant difference.

Effect sizes were calculated using Cohen's d and Hedges' g. For Imagery, Cohen's d was 0.21 (with Hedges' g at 0.18), while for Concreteness, Cohen's d was 0.09 (with Hedges' g at 0.08). These effect sizes suggest small to negligible practical significance.

As in the two previous experiments, items were scored as correct irrespective of the order of recall as participants were instructed to recall freely. TIV was also calculated and the first and last words were omitted as, again, the inter stimulus intervals between START and the first word and the last word and STOP did not confirm to the logarithmic spacing schedule that was intended. Hence, the abscissa for the TIV figures is 1-6 items (omitting word 1 and word 8). As can be seen from Fig. 4.2, the percentage of recall for the equal ISI condition roughly resembles the typical dipped serial position curve with more recall for the end-of-list items and lower recall for the items in the middle. A polynomial trend line drawn for the equal ISI curve (y = 3.1682x2 - 27.108x + 96.29; R^2 = 0.5291) indicates that there are larger fluctuations in the percentage of recall for the different serial positions (equal ISI curve not tending towards 0) as compared to what will be seen in the decreasing ISI curve.

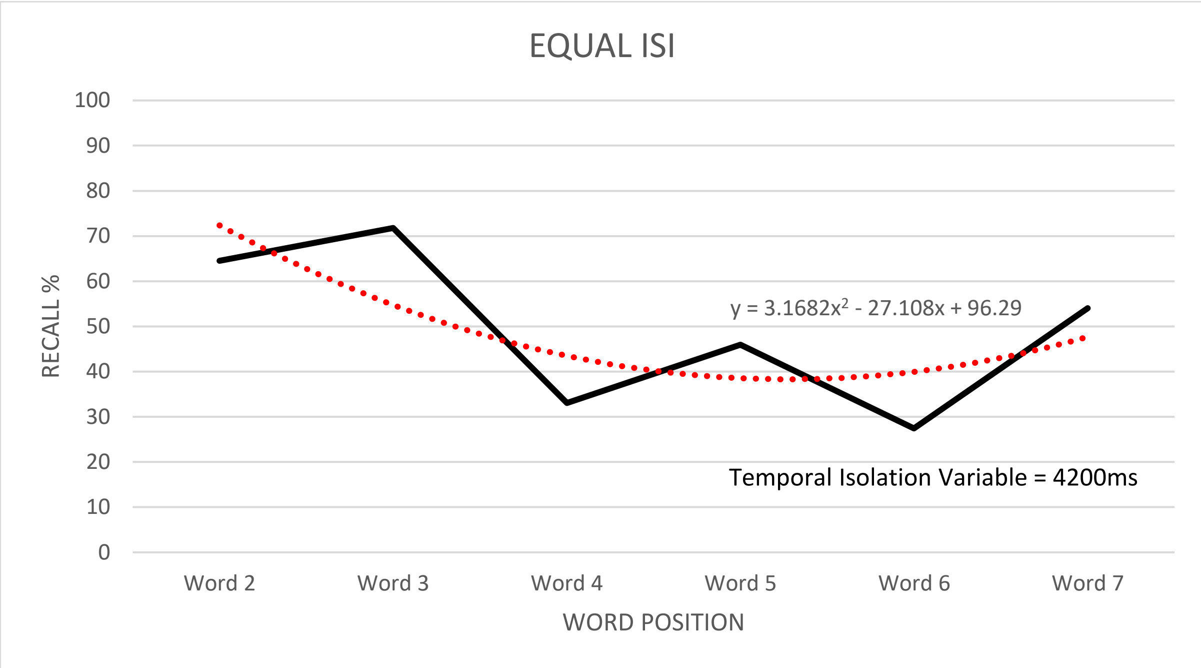

Figure 4.2 The percentage of recall for the Equal ISI condition as a function of Temporal Isolation Variable for the different word positions. The dotted line is the polynomial trend line for the data (see text).

4.3.1 Temporal Contraction

In this experiment, unlike the previous two experiments, only the decreasing ISI condition (temporal contraction) was considered and compared to the equal ISI condition. Now, when the temporal contraction curve is compared to the polynomial trendline of the data from the decreasing ISI condition, it is almost the same indicating that temporal isolation has a significant influence on the recall of the items when presented in a decreasing spacing schedule. In this experiment, the data was not fitted to the SIMPLE model as the data obtained was in the form of percentage of words recalled. Instead, only a polynomial trendline was utilised for visual analysis.

A paired sample t test revealed a significant difference in the scores for equal ISI condition (M = 4.40, SD = 1.29) and decreasing ISI condition (M = 4.66, SD = 1.34); t(124) = -1.7, p = 0.003. This indicates that the overall recall is significantly higher for decreasing ISI condition (please see Appendix for table).

The decreasing ISI curve is, however, more interesting and is consistent with the results of the previous experiments. It can be observed in Fig. 4.3 that there is a steady decrease in the percentage of recall for the words as the TIV decreases. Words 2, 3 and 4 are the words with the highest TIV and their recall was the highest (~ 81% – 53%), whereas the temporally crowded items with the lowest TIV (Words 5, 6 and 7) had the lowest recall (~ 50% - 40%). A polynomial trend line ($y = 0.8497x^2 - 13.113x + 88.79$; $R^2 = 0.7748$) for the decreasing ISI curve indicates that the curve is flatter with fewer variations (decreasing ISI curve is tending towards 0) than the equal ISI curve. The flatter curve seen with the decreasing ISI condition looks promising for the hypothesis of the present study that logarithmically decreasing the gaps between the presentation of items leads to a flatter serial position curve.

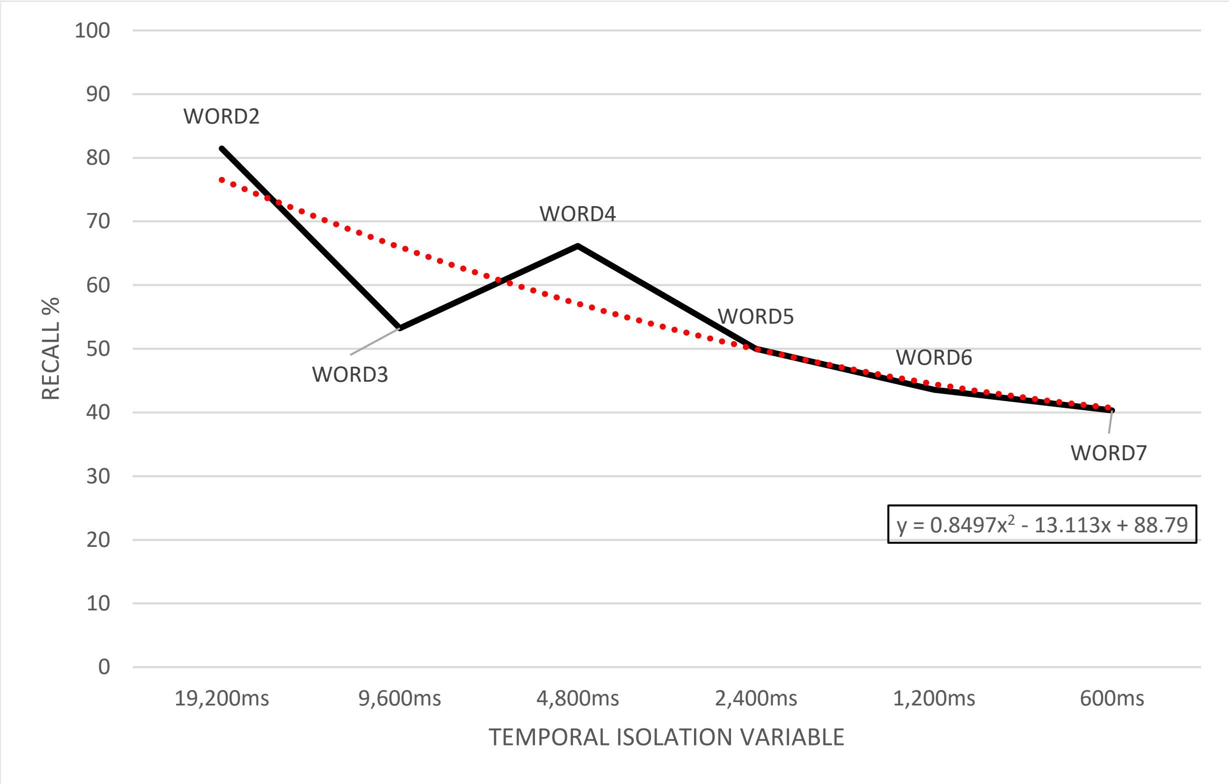

Figure 4.3 The percentage of recall for the Decreasing ISI condition as a function of Temporal Isolation Variable for the different word positions. The dotted line is the polynomial trend line for the data (see text).

Overall, this experiment agrees with and confirms the results of the previous experiments for a much larger sample size with fewer trials reducing proactive interference.

4.4 Items 1 and 8

As noted above, items 1 and 8 had to be considered separately from the rest of the stimuli in the list because a TIV calculation could not be made for these items. On the equal ISI schedule, the recall for item 1 was approximately 78% and for item 7, it was approximately 65%; on the decreasing ISI schedule, recall for item 1 was much higher (~85%) and for item 7, it was approximately 45%. The results cannot be interpreted in terms of the spacing schedule; yet it is apparent that a higher TIV is associated with the higher performance for item 1 in the decreasing ISI schedule.

4.5 Discussion

The results of Experiment 3 provide support for the temporal distinctiveness theory, which posits that the spacing of items in memory can significantly affect recall performance. This experiment specifically addressed the impact of decreasing inter-stimulus intervals (ISIs) on recall, contrasting this with an equal ISI condition to explore how temporal spacing influences memory.

The equal ISI curve is similar to the typical dipped serial position curve seen in numerous previous studies (and of course, to the present Experiment 1). The far more interesting curve is the decreasing ISI curve which does not show the usual dipped curve. Additionally, confirming the results of the previous two experiments, it also shows higher recall for the items with higher TIV and the recall decreases as TIV decreases with lowest recall for the most recent item (item 7) despite it being free recall. The demonstrated flatter serial position curve for the decreasing ISI condition is also similar to the curve seen for the decreasing ISI condition (controlled for articulatory rehearsal) in the previous two experiments. As can be seen, the polynomial trendline shows a dipped curve for equal ISI with a flatter curve for the decreasing ISI curve. Another important finding in this experiment was the fact that the overall performance in the decreasing ISI condition was significantly better than the equal ISI condition, suggesting that temporal isolation and possibly, the compressive spacing schedule of the items have contributed to enhanced recall.

As discussed in the Introduction (*see section 1.2.3*), Baddeley & Scott (1971) conducted a single-trial study designed to minimise or eliminate all forms of interference (retroactive, proactive and intra-sequence), most notably, proactive interference. It can be argued from the results of Experiment 3, that proactive and to some extent retroactive interference has been minimised by the utilisation of this paradigm leaving largely the influence of the temporal spacing schedule applied to the verbal memoranda. The present experiment provides evidence for a clear distinction between the recall curves for both temporal spacing conditions. This concurs with other studies (Welte & Laughery, 1971; Neath & Crowder, 1990; Brown et al., 2006) that have shown a beneficial effect on recall for the decreasing ISI presentation of stimuli.

In this study, the decreasing ISI condition, characterized by a logarithmically decreasing temporal gap between successive words, resulted in a flatter serial position curve compared to the equal ISI condition. This aligns with the temporal distinctiveness theory, which suggests that increasing the temporal distinctiveness of items—by varying the ISI—improves recall performance by making each item more temporally distinct from its neighbours (Tharp, 1971; Neath & Crowder, 1990). The flatter serial position curve in the decreasing ISI condition indicates that participants were able to recall items more consistently across different positions in the list, demonstrating the effectiveness of temporal distinctiveness in reducing the typical recency effect and improving recall.

The polynomial trendline analysis of the decreasing ISI curve revealed a smooth, consistent decline in recall as the TIV (Temporal Isolation Variable) decreased. Specifically, items with higher TIV (i.e., those presented earlier with longer ISIs) had higher recall rates, while items with lower TIV (i.e., those presented more recently with shorter ISIs) had lower recall rates. This result confirms the temporal distinctiveness hypothesis, which argues that longer intervals between items provide better opportunities for encoding distinct memory traces, thereby enhancing recall (Brown, Neath, & Chater, 2006). This phenomenon is evident as the decreasing ISI condition maintains higher recall rates for items presented at the start of the sequence compared to those presented at the end.

In contrast, the equal ISI condition produced a traditional serial position curve with a pronounced dip in recall for middle items, consistent with classic findings in memory research (Murdock, 1962). This dip reflects a typical serial position effect where items at the beginning and end of the list are recalled better than those in the middle, a pattern that is less pronounced in the decreasing ISI condition. The consistent performance across different serial positions in the decreasing ISI condition suggests that the temporal spacing provided by decreasing ISIs reduces the interference effects typically observed with equal ISIs.

The significant difference in overall recall performance, with higher recall in the decreasing ISI condition compared to the equal ISI condition, underscores the advantage of decreasing ISIs in memory tasks. This finding suggests that compressing the spacing between items in a logarithmic manner not only aids in recall by increasing temporal distinctiveness but also minimizes proactive interference (Baddeley & Scott, 1971). The overall better performance in the decreasing ISI condition highlights the practical benefits of manipulating temporal spacing to enhance memory recall.

The results from Experiment 3 align with previous studies demonstrating the benefits of decreasing ISI schedules. As previously mentioned, research by Welte and Laughery (1971) and Brown et al. (2006) has shown that varying the temporal spacing of items can improve recall by reducing the overlap of memory traces and enhancing distinctiveness. The present findings extend this literature by confirming that decreasing ISI not only improves recall but also results in a flatter serial position curve, which contrasts with the typical dipped curve observed with equal ISIs.

While the current experiment provides strong evidence for the impact of temporal distinctiveness on recall, it is important to note some limitations. The study did not account for potential individual differences in memory capacity or strategy use, which could influence recall performance. Future research could explore these variables and examine whether the benefits of decreasing ISI are consistent across different populations or memory tasks.

In summary, Experiment 3 provides reasonable evidence supporting the temporal distinctiveness theory by demonstrating that a decreasing ISI schedule enhances recall performance and results in a flatter serial position curve compared to an equal ISI schedule. These findings underscore the significance of temporal factors in memory and suggest practical applications for optimizing memory retention through the strategic manipulation of temporal spacing.

Chapter 5 - The question of non-verbal memoranda

5.1 Introduction to Experiment 4

This chapter further explores the central questions in this thesis – Does the decreasing spacing schedule enhance memory for a list of to-be-remembered items and improve the possibility of all items in the list being remembered equally? Experiments 1, 2 and 3 have suggested that temporal isolation has a beneficial effect on recall of a list of items. The above experiments have also explored the role of rehearsal and refreshing in conjunction with temporal isolation, showing that they interact significantly to determine recall. Furthermore, by testing various spacing schedules, the previous experiments demonstrated a slight benefit of the decreasing spacing schedule, although this remains to be investigated further. Additionally, thus far, the experiments in the previous chapters have employed verbal memoranda and this has admittedly delivered some promising results providing preliminary answers to the above questions. However, it was also observed that verbal memoranda may not be sufficient to test our theory in depth and that it is constrained by confounding variables such as rehearsal and refreshing.

In the present experiment, Experiment 4, instead of using words that can be rehearsed verbally, images were used and specifically, Chinese characters. The nature of the participants' responses and in turn, the data collected in this study will then, necessarily change from recall to recognition. The very characteristic of non-verbal memoranda that reduces confounding variables like rehearsal, makes a reliable measure of recall, impossible. Therefore, recognition was measured instead of recall. Another change from Experiments 1, 2 and 3 is that the "strength" of the memory trace was also tested. Instead of the attempted recall of the whole list, the task was to indicate whether a single test or 'probe' character had been present in the list: on half of trials this matched an item in the list (positive probes) and on half, it was novel (negative probes). Speed of response was taken as a measure of the strength of the memory trace for 'present list items' according to their position in the list. Similar to Experiment 3, the continued focus was on decreasing ISI condition and the equal ISI condition was administered as a control condition. Participants were divided into 2 groups; one group were shown stimuli with Decreasing ISI and the other group were shown stimuli with Equal ISI. The decreasing ISI condition is the one in which the distortion in memory will be reversed, according to our theory. In the present experiment, although there was more than a single trial, the effort was made to limit the number of trials to reduce interference (proactive and retroactive). The number of trials were limited to 2 experimental blocks with 5 trials each. Exposing participants to as limited a number of trials as possible was also the reason for dividing the participants into two groups instead of employing a within-subjects design where all the participants were shown both conditions. The reader will note a difficulty that the experimenters encountered while trying to balance limited trials with having enough data for each serial position. The limited number of trials meant that there were only 1 data point available for analysis for each serial position and the limitations of this are explained more in detail in the results section of the present study.

In this experiment, it is predicted that non-verbal memory would also benefit from temporal isolation. Additionally, it is suggested that, due to the inherent nature of non-verbal memoranda being less susceptible to confounding factors, the flattening of the serial position curve would be more prominent in the decreasing ISI schedule of this experiment.

5.2 Methodology

5.2.1 *Participants.*

Sixty-two volunteers (9 males and 53 females) were assigned alternately to two groups (each group with thirty-one participants), **Group 1** – Equal ISI and **Group 2** – Decreasing ISI. They were recruited from the University of Leeds participant pool in exchange for course credits and from the University of Leeds Psychology Volunteer pool in exchange for payment. Their average age was 22.6 years, they had normal/corrected-to-normal vision, were not previously familiar with Chinese characters and had not been diagnosed with a neurological problem.

5.2.2 *Stimuli.*

75 images of Chinese characters taken from an online repository and divided into a practice block and 2 experimental blocks. These stimuli were single characters of the same font and were chosen after initially being presented to 5 participants whose data are also included in the present experiment. Informal ratings (0-5) on familiarity and visual complexity were obtained for the stimuli as a whole and the stimuli selected were deemed satisfactory for the present experiment.

5.2.3 *Materials and Design.*

The experiment was designed on E prime so as to record responses and to measure accurate response times. All stimuli were presented on the centre of the screen, in a 60-point font for 2000ms. Each trial consisted of 5 novel Chinese characters not including the start and stop symbols which were also Chinese characters but recognisable shapes (Eg- start looked like a square and stop looked like a horizontal line). There were 2 blocks of five such trials each. The Inter-stimulus interval (ISI) between individual words was manipulated to create only two item lag conditions - decreasing ISI with 3200, 1600, 800, 400, 200, 100ms ISIs from Start symbol to Stop symbol; equal ISI with 1050ms ISIs from Start symbol to Stop symbol. Participants were divided into two groups. They were allotted to groups alternatively. Eg Participant 1 in Group 1, Participant 2 in Group 2, Participant 3 in Group 1 and so forth. Group 1 had the equal ISI experimental condition and; Group 2 was presented with decreasing ISI condition. Thus, this experiment also employed a between-subjects design.

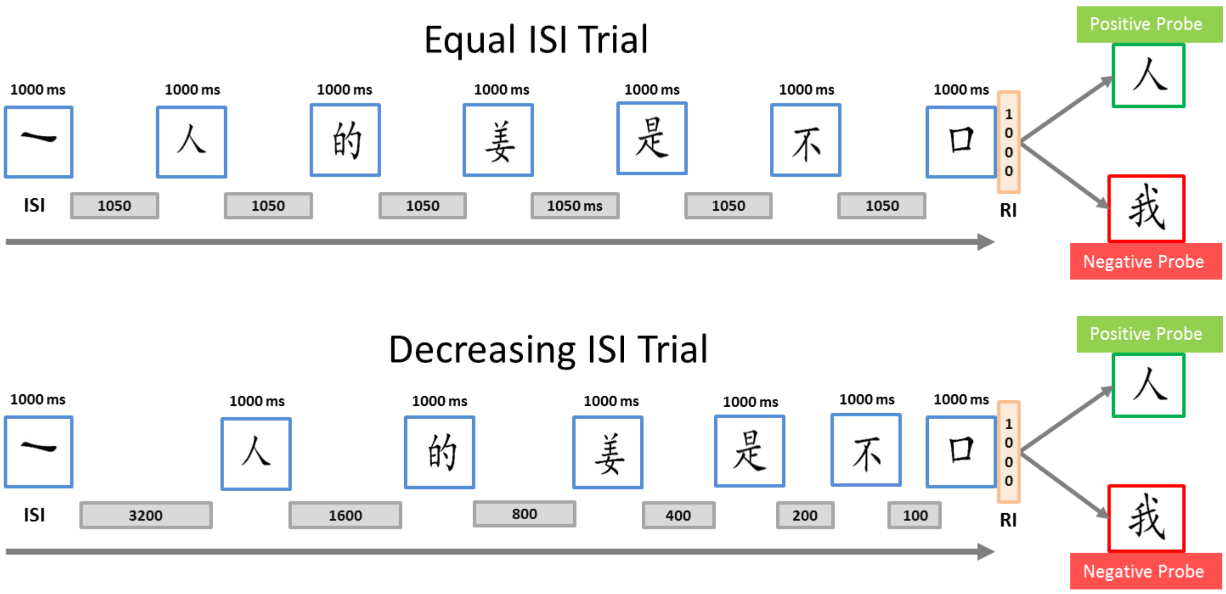

Figure 5.1 Inter Stimulus Intervals (ISI) in the two different item lag conditions (Decreasing ISI and Equal ISI)

5.2.4 Procedure.

As previously explained, participants were divided into 2 groups. Both groups completed a simple computer administered visual recognition memory task consisting of one practice block and 2 experimental blocks. The practice block consists of 3 trials. In each experimental block, there are 5 sets of 5 images of Chinese symbols each. Each set will begin with the start symbol and end with stop symbol. At the end of each set, participants were presented a probe item for recognition to which they had to indicate by single keypress response (Y and N) whether (1) they knew that the item had not been presented on the list (no), (2) they remembered that the item had been presented (yes). They were also asked whether they could remember which position the probe item appeared in the list by pressing a number from 1 to 5 (there are 5 positions altogether) or if they had responded no to the previous question, they were to press 0 instead. Each group of participants completed 2 experimental blocks (10 trials per item lag conditions). Each experimental block was separated by a break (minimum length of 3 minutes). The experimental session lasted no longer than 20 minutes (including breaks). Experimenter was present in the cubicle where they were tested individually.

5.3 Results

The responses were recorded on Eprime as an Edat file which gave the accuracy of response as well as the speed of response. There were four categories of scores that we collected – Accuracy, Response Time (RT), Position Accuracy (PA) and Position Response Time (PRT). The data from 3 participants were excluded as they were outliers; hence the results for 59 participants are reported.

Fig. 4.2 illustrates the overall accuracy for all serial positions and the accuracy was quite high (~ 80%). At first glance, it can be seen that the equal ISI curve looks very similar to the typical serial position curve, apart from the very high percentage of accuracy (90%) for SP3 (explained later) and the decreasing ISI curve looks like the decreasing ISI curves that was obtained from our previous experiments i.e. the percentage of accuracy increases with increase in the TIV of the item. Accuracy of response for decreasing ISI shows a higher percentage of accuracy (83% and 93%) for the serial positions with higher TIV (SP1 and SP2). This shows a beneficial effect of TIV in the recall of non-verbal items as well. SP4 in decreasing ISI also continues with the downward trend of the curve (59% accuracy), whereas, here a slight recency effect was seen in the slight rise of accuracy (72%) of SP5, the last item.

The equal ISI has shown an irregular value for SP3. To gain insight into the cause for this irregularity, the stimuli were re-examined where the particular stimulus shown as SP3 was a familiar shape which made it instantly recognisable. Due to this flaw, the percentage of recall showed a ceiling effect only for that particular serial position, essentially confounding the results. Since the confounding factor could not be removed, due to the availability of only one data point per serial position (previously explained in section 5.1), the results had to be interpreted with caution.

However, an attempt has been made to examine the polynomial trendline for the accuracy in decreasing ISI and equal ISI conditions by removing the potentially confounding SP3 stimulus. We can see in Fig. 4.2 that the trendline now looks similar to those obtained in previous experiments. A polynomial trend line of accuracy drawn for the equal ISI curve without SP3 ($y = 0.0075x^2 – 0.1045x + 0.9725$; $R^2 = 0.3538$) shows the familiar dipped U shaped curve; as opposed to the polynomial trend line for decreasing ISI which is flatter ($y = 0.0725x^2 – 0.3535x + 1.0825$; $R^2 = 0.9979$).

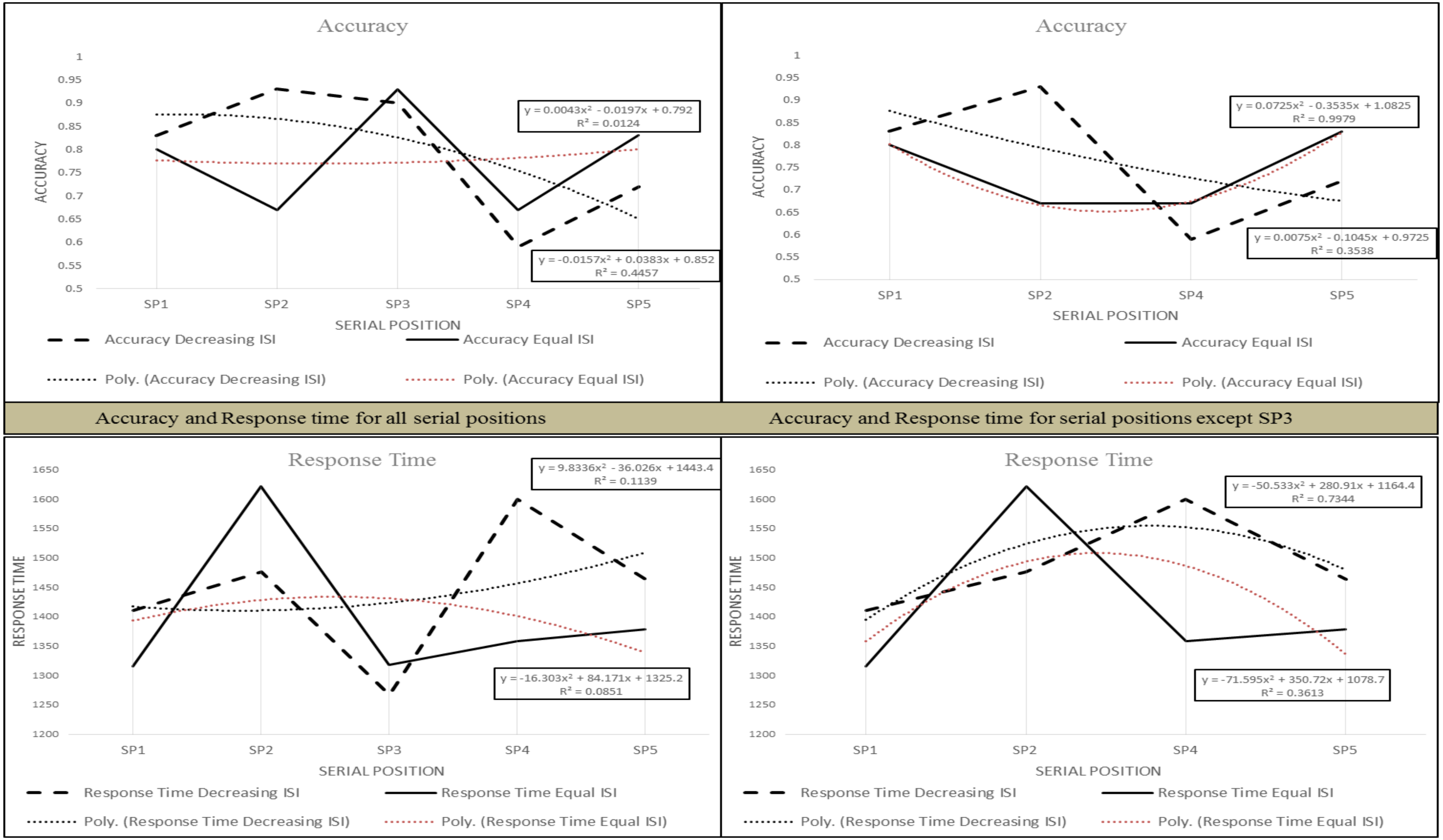

Figure 5.2 Accuracy of response and response time for all serial positions with and without serial position 3 (also showing TIV) in decreasing ISI and equal ISI

Response Time indicates the strength of the memory trace. Fig. 5.2 tells a story similar to the figure describing accuracy of response. The lower the RT, the stronger the memory trace and therefore, in DISI, it was again observed that the serial positions that are temporally well spaced out (SP1 and SP2) have a lower RT (1410-1475 ms) and SP4 which has a lower TIV has higher RT (1600 ms) with a slight recency effect seen for SP5 which has lower RT (~ 1463 ms). In the EISI curve, however, the recency effect is more pronounced, as the RT obtained is lower (1358 ms - 1378 ms) for SP4 and SP5. RT is also very low for SP1 which is unexpected but if the previous figure and this one was compared, then the accuracy for SP1 in EISI was marginally lower than that in decreasing ISI which means that although a lesser percentage of participants got SP1 accurately but those who did, had really strong memory traces of it.

The position of a correctly identified probe was reported similarly in both decreasing ISI and equal ISI as can be seen from Fig. 5.3. There was not much difference in Position Accuracy in both conditions with the PA being only marginally better for decreasing ISI. Both curves resemble a typical serial position curve with the exception of SP3 (~ 70% position accuracy) which could be because of the stimulus' highly identifiable nature, as explained earlier.

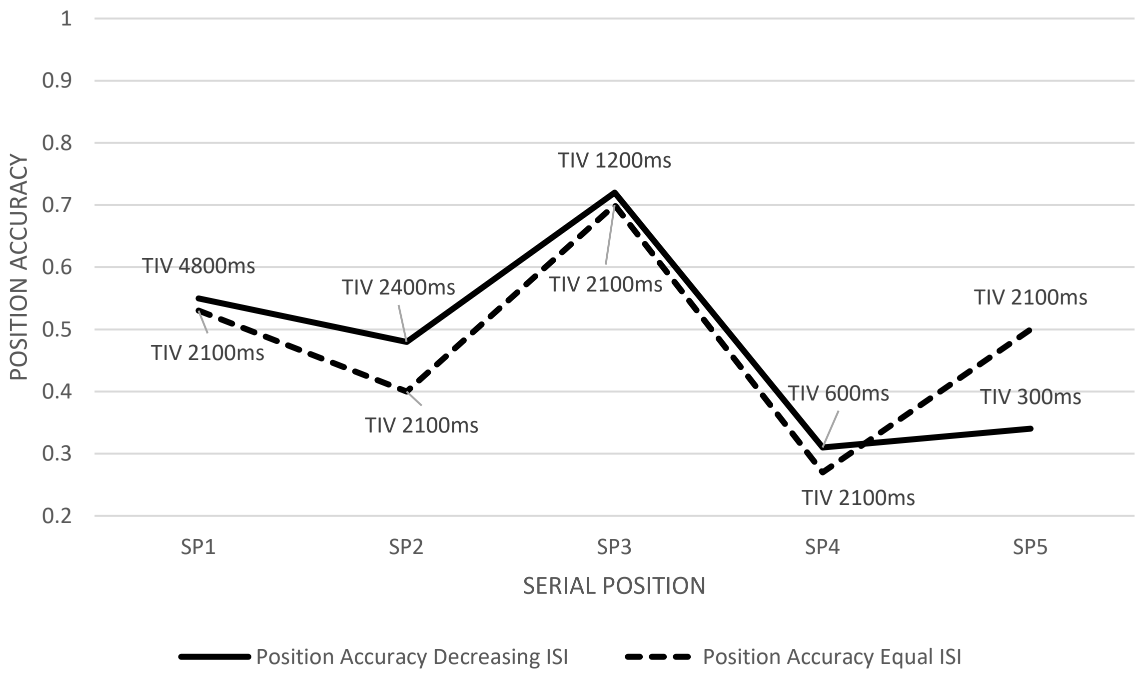

Figure 5.3 Position Accuracy for all serial positions (also showing TIV) in Decreasing ISI and Equal ISI.

The time taken on average by participants to correctly identify the serial position of a positive probe was somewhat different from the rest of our results. As seen in Fig. 5.4, in decreasing ISI, the items which had higher TIV (SP1 and SP2) had a higher PRT (1560ms – 1600ms) as compared to the PRT (1300ms – 1100ms) for items that had lower TIV (SP4 and SP5). This indicates that, for the items with a higher TIV, it took longer to correctly identify which serial position it was shown in. This may again indicate a recency effect as it would have been easier to correctly identify the position of more recently shown items. With regards to equal ISI, the curve for PRT does not point to a particular trend but that maybe because of the skewed SP3 result.

An independent samples t test comparing the means of the decreasing ISI group and the equal ISI group found that accuracy for serial position 2 in decreasing ISI (M = 0.93, SD = 0.26) than equal ISI (M = 0.66, SD = 0.48) and; t (57) = -2.62, p = 0.01 (please see Appendix for table). A repeated measures ANOVA with factors of 5 (serial position) between subjects factors of 2 x (item lag condition) with a Greenhouse-Geisser correction applied revealed reliable main effects of serial position on three variables; Accuracy (F (3.47, 198.3) = 3.9, MS_e = 0.18, p = 0.007, ηp^2= 0.06), Response Time (F (3.37, 192.56) = 3.13, MS_e = 318763.29, p = 0.022, ηp^2= 0.05), Position Accuracy (F (4, 228) = 6.66, MS_e = 0.22, p < 0.001, ηp^2= 0.1) but not on Position Response Time. This has to be interpreted with caution due to the ceiling effect observed on serial position 3. Furthermore, no significant interaction was found between the item lag conditions (equal ISI and decreasing ISI) on any of the variables. Further Post hoc tests revealed that, indeed, serial position 3 (M= 0.92, SD = 0.28; M = 1314.5, SD = 647.7) was recalled better and faster than serial position 4 (M= 0.63, SD = 0.49; M = 1614.5, SD = 754.6).

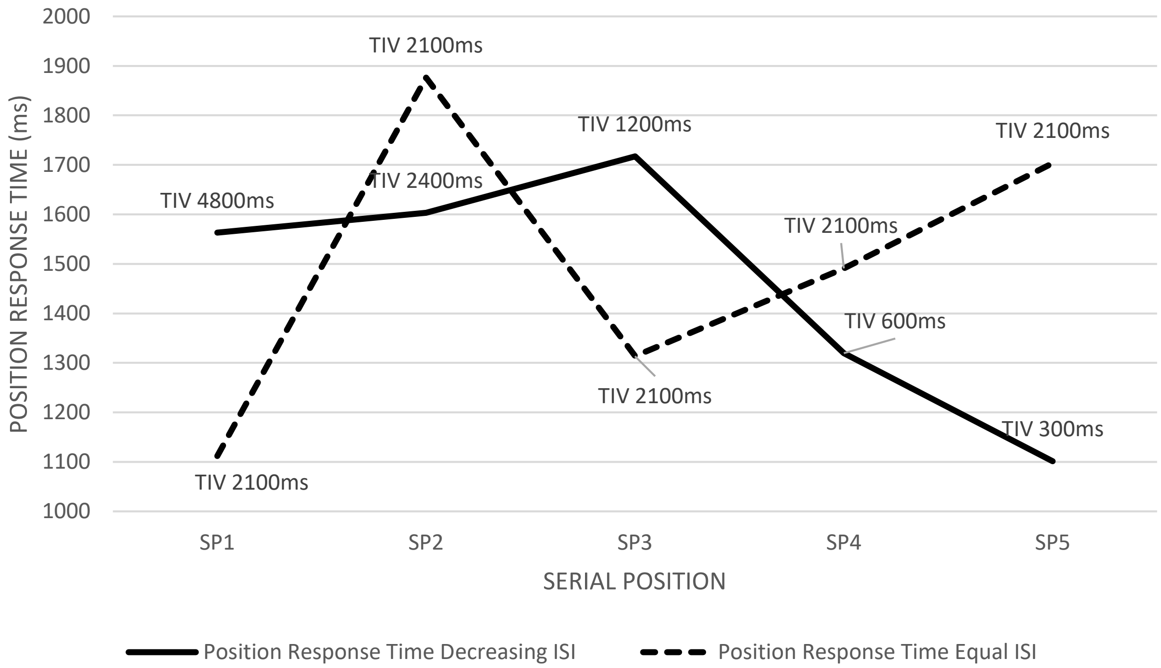

Figure 5.4 Position Response Time for all serial positions (also showing TIV) in Decreasing ISI and Equal ISI.

5.4 Discussion

As mentioned in the Results section, the findings in this experiment have to be interpreted with caution as the stimulus shown for serial position 3 seems to have been instantly recognisable, hence confounding our results. However, the rest of our results still show some interesting patterns. The main point of discussion is the effect of temporal isolation seen even in non-verbal sequential memory. We have seen in the decreasing ISI schedule that serial positions that are temporally isolated have a better chance of being recognised and remembered when cued. Apart from the slight recency effect seen for the last item (SP5) and the high recognisability of our third item (SP3), our serial position curve shows a decline in recognition of those items with lower TIV. Although some studies have suggested that there is no influence of temporal isolation on non-verbal memory (Parmentier et al., 2006; Nimmo and Lewandowsky, 2006), these results are largely consistent with many other studies which have also seen a positive influence of temporal distinctiveness for non-verbal memory (Souza and Oberauer, 2015; Mercer, 2014; Mammarella et al., 2002; Avons, 1998). The strength of the memory traces as indicated by the response times, also shows a similar effect of TIV in that the memory traces are stronger when the items are temporally well spaced out. Hence, it might indicate better encoding and output of the memory item when it is temporally discriminable from each other. Being able to correctly identify the position of the positive probe shown also revealed the influences of temporal isolation as seen in the decline of position accuracy with lower TIV (with the exception of SP3). The effect of recency overrides the effect of temporal isolation when it came to the response times for identifying the correct position of a positive probe. This is as seen in Fig. 19 where the response times seems to be higher for the earlier items in the sequence as compared to the more recent items.

The analysis of the serial position curve for accuracy of recognition seen in this experiment is a really fascinating since serial position curves for visual or non-verbal memory has been explored very little thus far. Although some studies (Avons, 1998; Broadbent and Broadbent, 1981) have found that serial position curves for visual or non-verbal memory, does not show the typical dipped curve but only a slight recency effect for the last item, numerous other studies have found a u shaped serial position curve (Hurlstone et al., 2014; Smyth and Scholey, 1996; Agam et al., 2010). The serial position curve in the present experiment shows a high performance for the first few items (except SP3) and the curve is declining as TIV decreases with a slight recency effect as seen by Avons (1998). However, unlike these previous studies, we think this could be attributed to temporal isolation and not to a primacy effect. It could also point to the reversal of distortion in memory using a negative compressive logarithmic spacing schedule leading to a flatter serial position curve apart from the slight recency effect for the last item. Avons (2007) claims that the serial position curve for non-verbal memory is generally flatter than that of verbal memory, but this has not been replicated or studied further. But this also seems not to be the case as is shown by our serial position curve with equal ISI showing the typical U-shaped curve. However, we have to note the fact that in our experiment, participants were asked to try and remember the position of the positive probe as well which could have led to verbalisation of the items in turn leading to a serial position curve similar to the ones seen in verbal memory. Overall, we do see a difference in the shape of the serial position curves with the different spacing schedules although it does not seem to be statistically significant. We need to conduct further experiments with more trials to be able to study the serial position curve better.

Chapter 6 - The question of schedules of presentation and retention intervals

6.1 Introduction to Experiment 5

This chapter examines not only the temporal spacing within the list of items but also the post-presentation interval. In other words, an attempt is made to understand the influence of time to recall after the presentation of varyingly scheduled lists of items on the recall of the items. Before outlining the present experiment, it is worth noting that the inclusion of a consolidation mechanism into models of forgetting remains controversial. For instance, Lewandowsky, Ecker, Farrell, & Brown (2012) refer to consolidation as an ‘invisible’ concept that is assumed to be present in the absence of forgetting; however, there seems to be very little concrete evidence of its presence. Often, studies will attribute the lack of forgetting over an extended time interval to consolidation, without any direct manipulation of the process (e.g. Ricker & Cowan, 2014). When short term consolidation is directly manipulated, it is unclear, despite a few attempts such as Bayliss et al. (2015), as to whether short-term consolidation for non-verbal memory works across one or two seconds or several seconds, and whether there is any justification for making a distinction between forms of consolidation and forms of maintenance such as rehearsal and attentional refreshing which was explored in earlier chapters.

Experiment 4 showed promising results with temporal isolation influencing non-verbal memory. However, this experiment had a few limitations. The limited number of trials created too few points of measurement for each serial position, in turn, leading to the results being confounded. Therefore, a more thorough exploration of memory for a list of non-verbal items was required and the present experiment aimed to do this by increasing the number of experimental trials.

In the present experiment, Experiment 5, Chinese characters were used as in the previous experiment. As in Experiment 4, recognition was measured instead of recall and included the speed of response to measure the strength of memory traces. It is similar to the previous experiment in that, the task was to indicate whether a single test or ‘probe’ character had been present in the list. However, in this experiment, the ratio of positive to negative probes was 2:1 so as to get more points of measurement. This experiment was conducted as separate parts and then combined. Here, instead of the Equal ISI condition, there was one group who was with presented only with the Decreasing ISI condition; another group was presented with both Decreasing ISI and Increasing ISI condition; and a third group, again with only the Decreasing ISI condition but with alternating retention intervals. It was hoped that by having a third group with alternating retention intervals, one shorter (1 sec) and another longer (7.5 sec), some light would be shed on the processes of consolidation. The decreasing ISI condition is the one in which the distortion in memory will be reversed, according to our theory. Therefore, the continued focus was on decreasing ISI condition and the increasing ISI condition was administered as a control condition.

In this experiment, it is predicted that non-verbal memory would benefit from temporal isolation and would replicate and refine the findings of the previous experiment. Additionally, it is designed to explore the influence of retention intervals and provide some insight into the factors contributing to consolidation of memory traces.

6.2 Methodology

6.2.1 Participants.

Fifty-one volunteers (9 males and 53 females) were divided into three groups (each group with seventeen participants); **Group 1** - Decreasing ISI trial only; **Group 2 -** Decreasing ISI trial and Increasing ISI trial alternately; **Group 3 -** Decreasing ISI trial with alternating Retention Intervals – 1 sec and 7.5 sec. They were recruited from the University of Leeds participant pool in exchange for course credits and from the University of Leeds Psychology Volunteer pool in exchange for payment. Their average age was 22.6 years, they had normal/corrected-to-normal vision, were not previously familiar with Chinese characters and had not been diagnosed with a neurological problem.

6.2.2 Stimuli.

700 images of Chinese characters taken from the same online repository and divided into a practice block and 1 or 2 experimental blocks.

6.2.3 Materials and Design.

The experiment was designed on E prime so as to record responses and to measure accurate response times. All stimuli were presented on the centre of the screen, in a 60-point font for 2000ms. Each trial consisted of 5 novel Chinese characters not including the start and stop symbols which were also Chinese characters but recognisable shapes (Eg- start looked like a square and stop looked like a horizontal line). There were 12 blocks of ten such trials each. Each participant came for 3 sessions (not more than 2 days apart) and in each session, they were presented with 4 experimental blocks. The Inter-stimulus interval (ISI) between individual words was manipulated to create only two item lag conditions - decreasing ISI with 3200, 1600, 800, 400, 200, 100ms ISIs from Start symbol to Stop symbol; increasing ISI with 100, 200, 400, 800, 1600, 3200ms ISIs from Start symbol to Stop symbol. Participants were recruited as three different groups. Group 1 was only shown the decreasing ISI trials; hence all 12 experimental blocks consisted of only stimuli presented at decreasing ISI condition. Group 2 was shown both decreasing ISI trials and increasing ISI trials; hence the 10 trials in each of the 12 experimental blocks were presented in the increasing ISI and decreasing ISI condition alternately. Additionally, for participants in Group 2, the first experimental block consisted of the practice block (which had three trials) and 4 experimental blocks which consisted of 3 sets of ten trials each. In every experimental block, the first set began with a decreasing ISI trial followed by an increasing ISI trial and so on alternatively. The second set began with an increasing ISI trial followed by a decreasing ISI trial and so on alternatively and the third set began with a decreasing ISI trial followed by an increasing ISI trial and so on alternatively. Group 3 was again shown only the decreasing ISI condition but with 2 different retention intervals (1 sec and 7.5 sec); hence the 10 trials in each of the 12 experimental blocks were presented in the decreasing ISI condition but with alternating retention intervals.

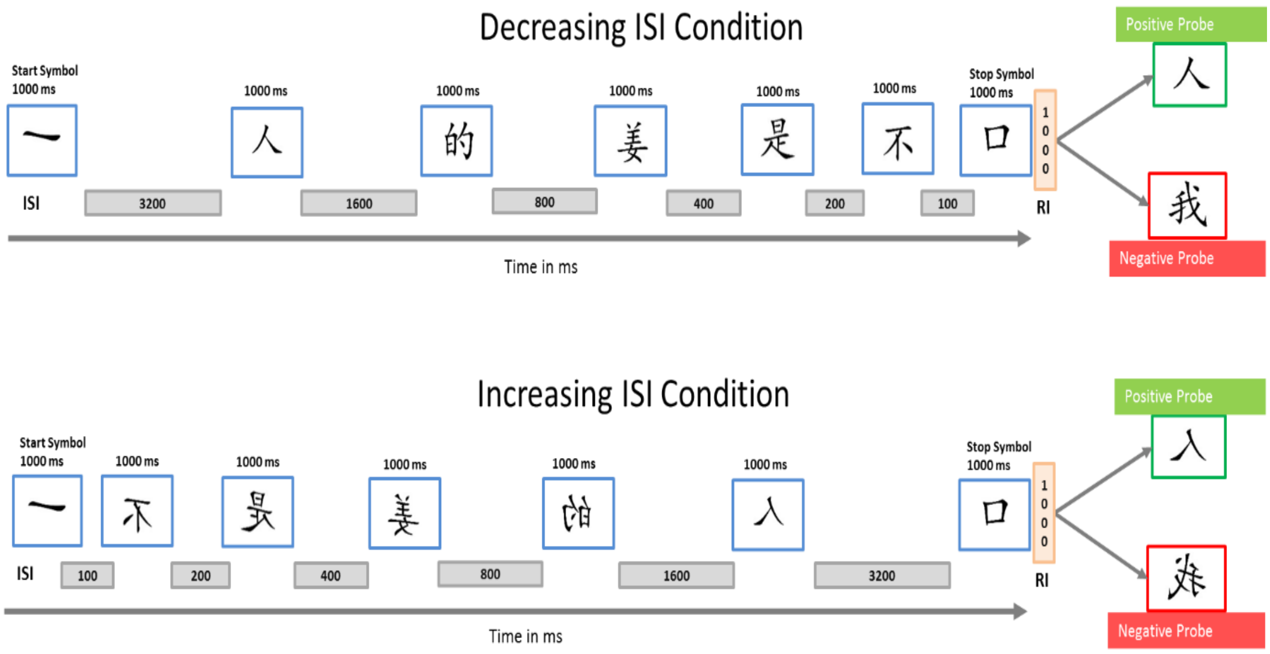

Figure 6.1 Different Inter Stimulus Intervals (ISI) in the two different item lag conditions (Decreasing ISI and Increasing ISI) in Experiment 4

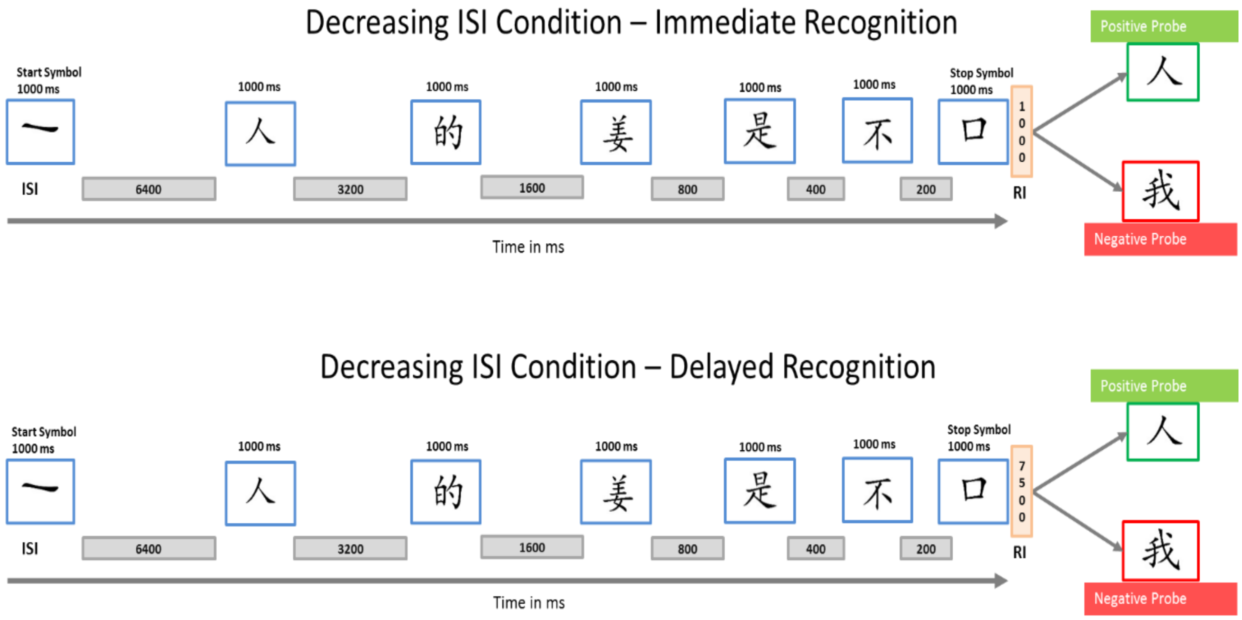

Figure 6.2 Different Retention Intervals (RI) – 1000ms and 7500ms in the Decreasing ISI item lag condition in Experiment 4

6.2.4 Procedure.

As explained, participants had been recruited as 3 groups. All three groups completed a simple computer administered visual recognition memory task consisting of one practice block and 12 experimental blocks. The practice block consists of 5 trials. In each experimental block, there are 5 sets of 5 images of Chinese symbols each. Each set began with the start symbol and end with stop symbol. At the end of each set, participants were presented a probe item for recognition to which they had to indicate by single keypress response (Y and N) whether (1) they knew that the item had not been presented on the list (no), (2) they remembered that the item had been presented (yes). Each group of participants completed 12 experimental blocks (60 trials per item lag conditions). Each experimental block was separated by a break (minimum length of 3 minutes). The experimental session lasted no longer than 60 minutes (including breaks). Experimenter was present in the cubicle where they were tested individually.

6.3 Results

As in Experiment 3, the responses were recorded on Eprime as an Edat file which gave us the accuracy of response as well as the speed of response. There were 3 groups and the results of the three groups were regarded separately at first and then altogether. There were two categories of scores that we collected – Accuracy and Response Time (RT).

6.3.1 Group 1 – Only Decreasing ISI

The results for the group that was only presented with Decreasing ISI trials for all the 12 experimental blocks is discussed first. Fig. 6.3 represents the accuracy of response for serial positions 1 to 5. The graph for the Decreasing ISI trial shows a flatter function. There is a good level of accuracy for all the serial positions (almost 60%). Serial position 5 has the highest accuracy with more than 80%. The figure shows that there is not much difference between the accuracy for serial positions 1-4. There is a slight rise in the accuracy in serial position 5.

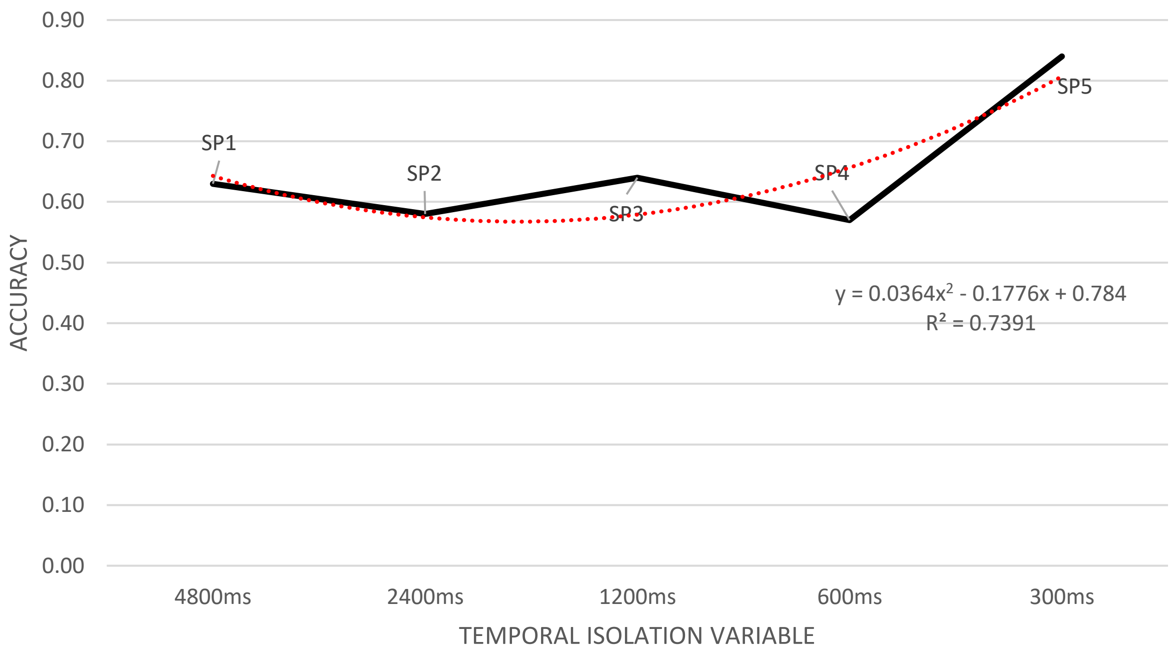

Figure 6.3 Accuracy of response for all serial positions (also showing TIV) in Decreasing ISI

There is a beneficial effect of TIV for some of the earlier serial position items and there is no significant dip in the curve with lower accuracy for serial positions 2, 3 and 4. However, the higher accuracy for serial position 5 still shows a recency effect as seen in the previous experiment.

A repeated measures ANOVA was conducted with the 5 serial positions as the factors and this revealed the main effect of at least one of the serial positions on accuracy of recognition of the probe item [F (4, 0.12) = 17.855, p <0.001, ηp^2= 0.53]. Further pairwise comparisons between the serial positions revealed that there was only a significant difference between serial positions 1 to 4 and serial position 5. This shows that accuracy remained the same for almost all serial positions, hence making the serial position curve flatter. Post hoc tests using the Bonferroni correction revealed a main effect of serial position 5 on accuracy (M= 0.86, SD = 0.027) and it was recognised significantly more accurately than all the other serial positions {i.e. serial position 1 (M = 0.66, SD = 0.037); serial position 2 (M = 0.59, SD =0.054); serial position 3 (M = 0.64, SD = 0.036); serial position 4 (M = 0.57, SD = 0.05)}.

The results for Response Time also convey a similar picture as illustrated in Fig. 5.4. This graph also shows a flatter function other than the lower response time for serial position 5. All the other serial positions identified accurately have a good response time (< 900 ms). This shows that the strength of the memory trace is good and similar for almost all the serial positions while being slightly higher for serial position 5 showing signs of recency effect.

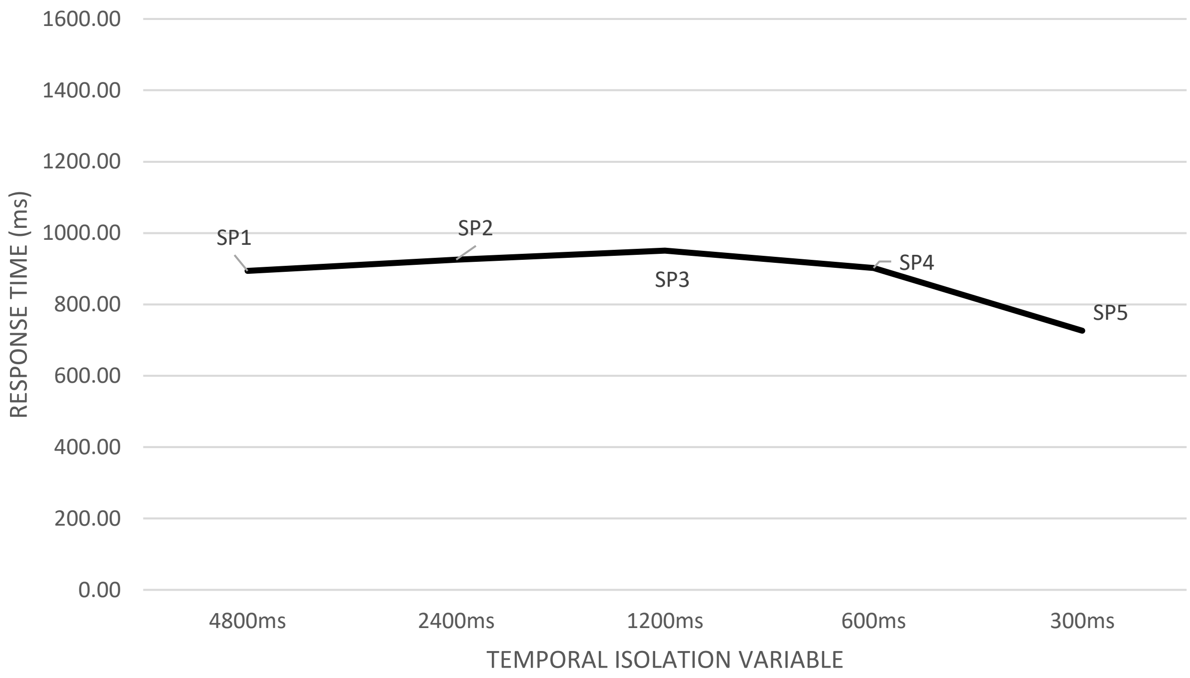

Figure 6.4 Response Time for all serial positions (also showing TIV) in Decreasing ISI

A repeated measures ANOVA for the 5 serial positions showed main effect of at least one serial position on response time [F (4, 64) = 8.683, p<0.001, ηp^2= 0.35]. Pairwise comparisons for the same revealed that similar to the results for accuracy, there was only a significant difference between serial positions 1 to 4 and serial position 5. Thus it can be concluded that the memory trace for all the serial positions was similarly strong except for serial position 5, for which the strength of the trace was significantly stronger. Post hoc tests using the Bonferroni correction revealed a main effect of serial position 5 on response time (M= 731.86, SD = 45.45) and it was recognised significantly faster than all the other serial positions {i.e. serial position 1 (M = 978.35, SD = 71.26); serial position 2 (M = 925.67, SD = 64.29); serial position 3 (M = 970.42, SD = 75.71); serial position 4 (M = 901.9, SD = 71.7)}.

6.3.2 Group 2 – Decreasing ISI and Increasing ISI

The results for the group that was presented with Decreasing ISI and Increasing ISI trials alternately is elaborated on in this section. Fig. 5.5 represents the accuracy of response for serial positions 1 to 5. The graph for the Decreasing ISI trial shows a higher accuracy of response for all the serial positions. There is a good level of accuracy for all the serial positions (> 60%). Serial position 5 has the highest accuracy in both item lag conditions (~ 80%).

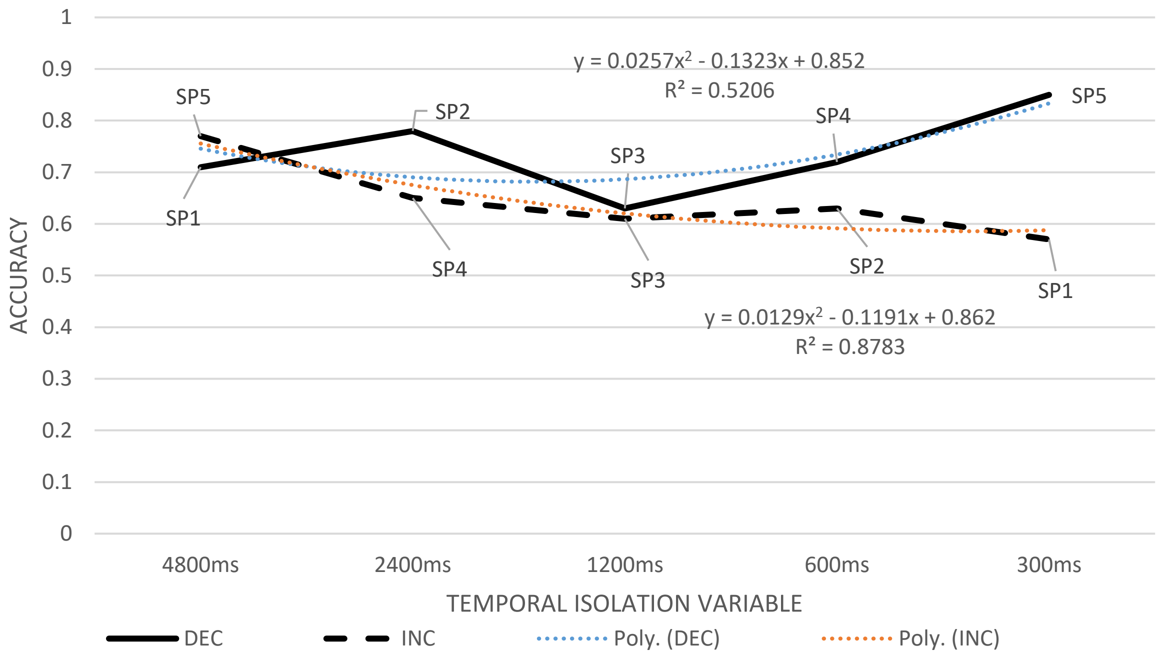

Figure 6.5 Accuracy of response for all serial positions (also showing TIV) for both item lag conditions (Decreasing ISI and Increasing ISI).

A beneficial effect of TIV is seen for the items in both the item lag conditions. However, the higher accuracy for serial position 5, for both increasing and decreasing ISI conditions, still shows a recency effect as seen in the previous experiment. The increasing ISI serial position curve shows very clearly the beneficial effect of TIV. The curve gradually but steadily goes up as the TIV for the stimuli also goes up. The decreasing ISI curve, on the other hand, has a higher overall accuracy of responses and even though there is a small dip in the accuracy for serial position 3, overall, there is a consistent level of accuracy throughout.

A paired samples t test was used to compare the means of accuracy and response time between the different item lag conditions (decreasing and increasing ISI). This showed a significant difference for accuracy with decreasing ISI (M= 0.738, SD = 0.122) and increasing ISI (M= 0.64, SD = 0.135) but not response time. This indicated that accuracy is significantly higher for the decreasing ISI condition which corresponds with what was seen in the graphical illustration {t (16) = 3.46, p<0.01)}. Please see Appendix for the table.

The results for response time are somewhat hazier as illustrated in Fig. 6.7. The overall response times for all the items in both item lag conditions seem to be higher than 1 sec but still lower than 1.5 sec. This is a slightly higher response time than seen in the previous group.

Also, in both increasing and decreasing ISI conditions, there is a slight increase in the time taken to recognise serial position 3. A strong memory trace is indicated by a lower response time and therefore, strength of the trace for serial position 5 is high in both the item lag conditions. The decreasing ISI function for response time shows a more consistent and uniform response time across all the serial positions as opposed to the increasing ISI function.

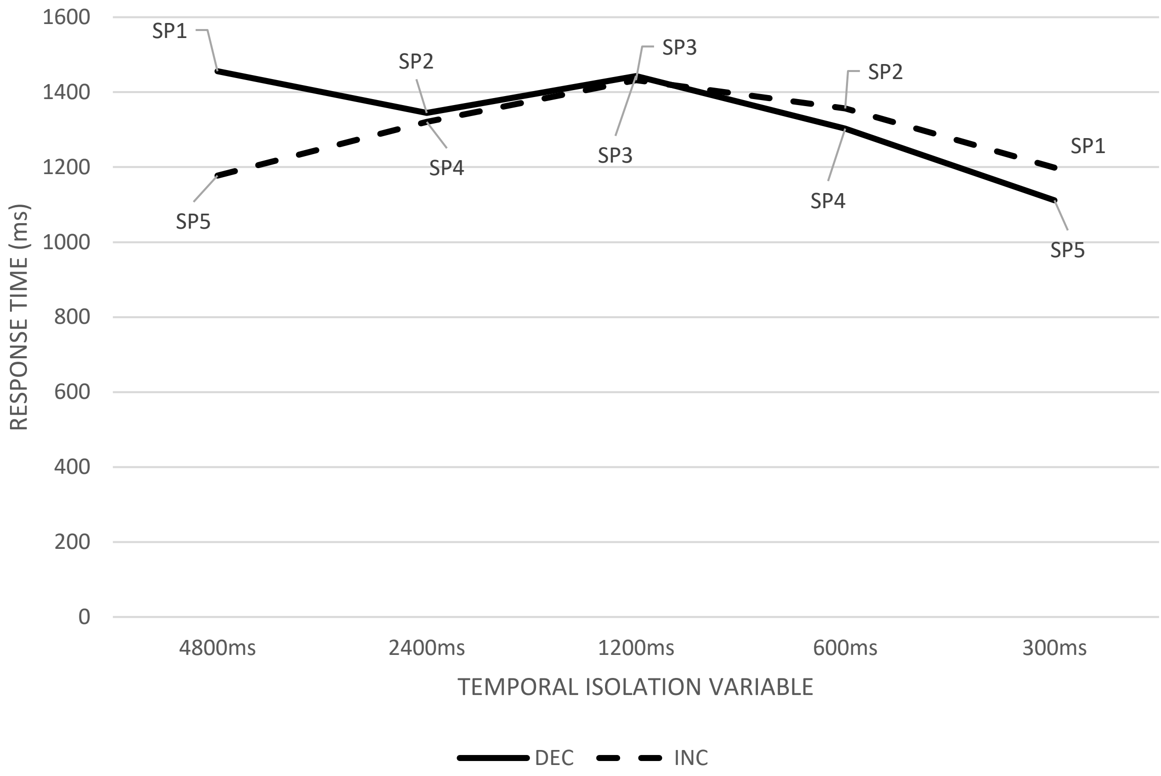

Figure 6.6 Response Time for all serial positions (also showing TIV) for both item lag conditions (Decreasing ISI and Increasing ISI)

The paired samples t test that was performed did not show a significant difference between decreasing and increasing ISI for response time (see appendix for table). This was also evident in the graphical illustration of the same.

Reliable main effects of the different item lag conditions on Accuracy [F (1, 16) = 10.79, p <0.010, ηp^2= 0.40] were revealed with a repeated measures ANOVA with factors of 5 serial positions x 2 item lag conditions. The ANOVA also showed main effects of serial position on both the variables - on Accuracy [F (4, 64) = 7.954, p<0.001, ηp^2= 0.33]; and on Response Time [F (4, 64) = 5.332, p<0.01, ηp^2= 0.25]. It did not, however, reveal any significant effects of the interaction between the item lag conditions and serial positions. Post hoc tests using the Bonferroni correction revealed a main effect of serial position 5 on accuracy (M= 0.82, SD = 0.03) was recognised significantly more accurately than all the other serial positions {i.e. serial position 1 (M = 0.64, SD = 0.03); serial position 2 (M = 0.71, SD =0.043); serial position 3 (M = 0.62, SD = 0.039); serial position 4 (M = 0.69, SD = 0.04)}. The post hoc tests also revealed a significant main effect of serial position 5 on response time (M= 1144.5, SD = 115.1) and it was recognised significantly faster than all some of the other serial positions {i.e. serial position 3 (M = 1437.77, SD = 138.56); serial position 4 (M = 1311.76, SD = 132.39)}. Most importantly, as predicted, they revealed a main effect of item lag condition on accuracy and but not on response time; the decreasing ISI condition was better for accuracy (M = 0.74, SD = 0.03) than the increasing ISI condition (M = 0.65, SD = 0.03).

6.3.3 Group 3 – Decreasing ISI with alternating Retention Intervals

This section elaborates on the results for the third group presented with only the Decreasing ISI condition but with alternating Retention Intervals (1 sec and 7.5 sec). Fig. 5.5 represents the accuracy of response for serial positions 1 to 5. The graph for the Decreasing ISI trial with a shorter Retention Interval (RI) shows a higher accuracy of response for all the serial positions except serial position 1 which is almost the same. There is a good level of accuracy for all the serial positions (> 60%) in the condition with shorter RI (1 sec) and for the condition with the longer RI (7.5sec), the accuracy is somewhat mixed (between 40 – 70%).

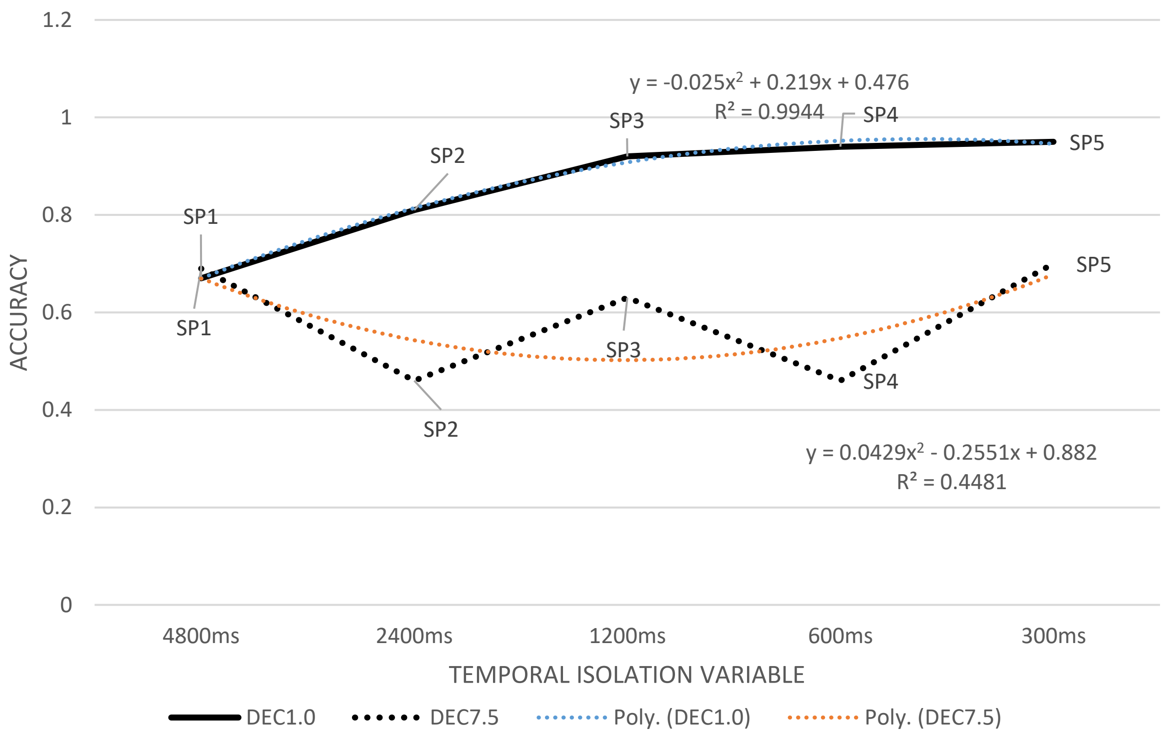

Figure 6.7 Accuracy of response for all serial positions (also showing TIV) in Decreasing ISI for both the Retention Intervals (1 sec and 7.5 sec).

In general, from the Fig. 6.7, one can note that accuracy was significantly higher for the Decreasing ISI condition with the shorter RI (1 sec). The effect of TIV, however, is a little more confusing in this experiment and it doesn't seem to show any significant pattern of effects for any of the serial positions. In the condition with the shorter RI (1 sec), the later serial positions (ones with less TIV) seem to be higher in accuracy which is not consistent with any of the previous experiments. Also, in the other condition (RI = 7.5 sec), we see very variable accuracy for all the serial positions and the TIV does not seem to have a consistent pattern of effects on the accuracy. One explanation for this could be that the RI has added to the temporal isolation of the last serial position, despite the STOP stimulus, thus making SP5 the serial position with the highest TIV. However, a more in depth examination of these results will be conducted in the discussion section of this chapter.

Comparison of the means for Accuracy and Response Time between the different conditions (decreasing ISI with RIs of 1 sec and 7.5 sec) was done using the paired samples t test. This showed a significant difference for accuracy with decreasing ISI – RI 1sec (M= 0.82, SD = 0.093) and decreasing ISI – RI 7.5sec (M= 0.56, SD = 0.169). This indicated that accuracy is significantly higher for the Decreasing ISI condition with shorter RI {t (16) = 8.27, p<0.001)}. Please see Appendix for table.

The results for response time are again somewhat hazier as illustrated in Fig. 6.8. The overall response times for all the items in both item lag conditions seem to be higher than 1 sec but still lower than 2 sec. This is a slightly higher response time than seen in the previous group. Also, in both different retention interval decreasing ISI conditions, there is a slight increase in the time taken to recognise serial position 3. A strong memory trace is indicated by a lower response time and therefore, strength of the trace for serial position 5 is high in both the item lag conditions. The decreasing ISI function for response time shows a more consistent and uniform response time across all the serial positions as opposed to the increasing ISI function.

The paired samples t test that was performed did not show a significant difference in response time between decreasing ISI with alternating RI (see appendix for table). This was also evident in the graphical illustration of the same.

Reliable main effects of the different retention intervals conditions on Accuracy [F (1, 16) = 74.22, p <0.001, ηp^2= 0.82] were revealed with a repeated measures ANOVA with factors of 5 serial positions x 2 retention interval conditions. The ANOVA also showed main effects of serial position on accuracy but not on response time; on Accuracy [F (1, 16) = 37.61, p<0.001, ηp^2= 0.7]; and on Response Time [F (1, 16) = 3.77, p = 0.07]. It also revealed significant effects of the interaction between the retention intervals and serial positions for accuracy [F (1, 16) = 15.09, p<0.001, ηp^2= 0.49] but not response time.

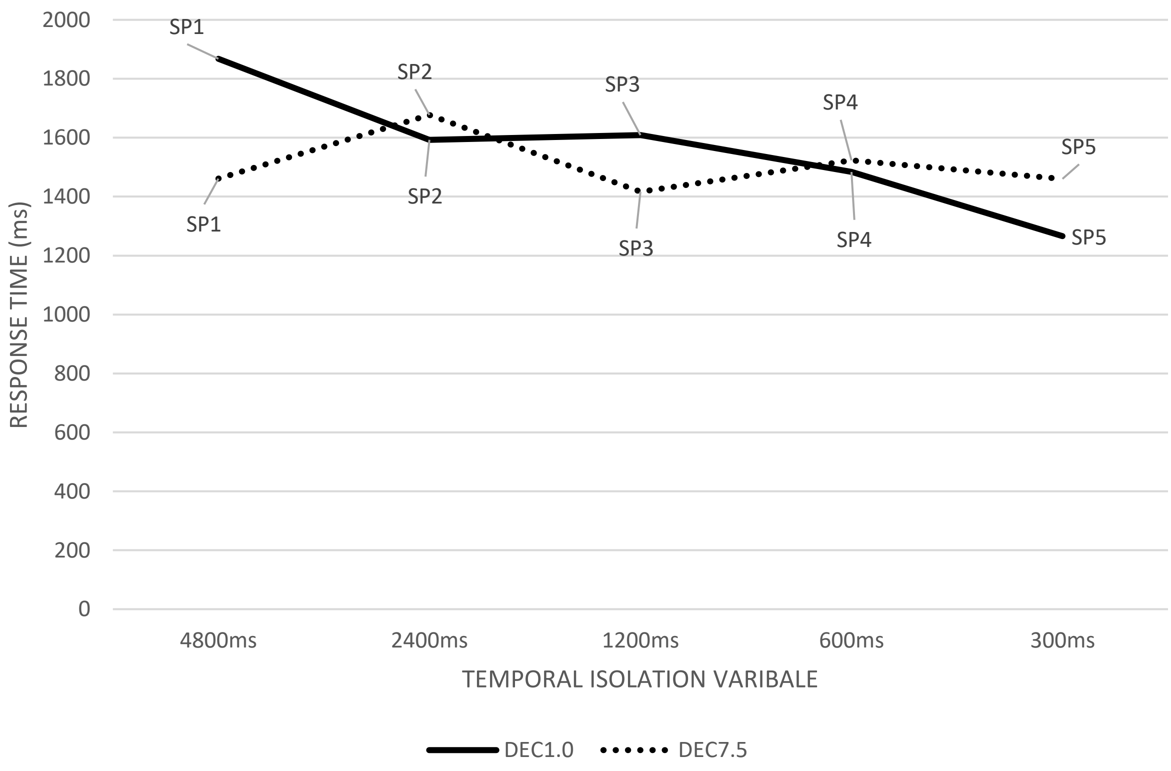

Figure 6.8 Response Time for all serial positions (also showing TIV) in Decreasing ISI for both the Retention Intervals

6.3.4 Comparison between the decreasing ISI trials of Group 1 and Group 3

A two-way repeated measure ANOVA between the decreasing ISI group with no RI and decreasing ISI group with 1 sec RI and with the factors of 5 x (item position) revealed reliable main effects of item position ($F (4, 128) = 22.05$, $MSe = 0.12$, $p < 0.001$, $\eta p2= 0.41$), and the interaction between item position and group condition ($F (4, 128) = 7.77$, $MSe = 1.64$, $p < 0.001$, $\eta p2= 0.2$).

Post hoc tests using the Bonferroni correction revealed that there was a significant difference between the total accuracy of recall in both the groups with higher accuracy in the decreasing ISI with 1 sec RI group (M = 0.83, SD = 0.029). It also showed that serial positon 5 (M= 0.89, SD = 0.02) was recalled significantly better than all the other serial positions {i.e. serial position 1 (M = 0.68, SD = 0.02); serial position 2 (M = 0.68, SD =0.03); serial position 3 (M = 0.76, SD = 0.02); serial position 4 (M = 0.71, SD = 0.03)}. Therefore, it can be inferred that serial has an effect on recall and that stimuli later in the list are more likely to be recalled.

A two-way repeated measure ANOVA between the decreasing ISI group with no RI and decreasing ISI group with 7.5 sec RI and with the factors of 5 x (item position) revealed reliable main effects of item position ($F (4, 128) = 19.17$, $MSe = 0.18$, $p < 0.001$, $\eta p2= 0.38$), but no effects of the interaction between item position and group condition.

Post hoc tests using the Bonferroni correction revealed that there was no significant difference between the total accuracy of recall in both the groups, but the accuracy was slightly higher in the decreasing ISI with no RI group (M = 0.66, SD = 0.04). It also showed that serial position 5 (M= 0.76, SD = 0.03) was recalled significantly better than all the other serial positions {i.e. serial position 1 (M = 0.63, SD = 0.03); serial position 2 (M = 0.54, SD =0.05); serial position 3 (M = 0.60, SD = 0.03); serial position 4 (M = 0.5, SD = 0.03)}. Therefore, it can be inferred that serial position has an effect on recall and that stimuli later in the list are more likely to be recalled.

An independent samples t test was performed between the decreasing ISI conditions in Group 1 and Group 3; namely between decreasing ISI condition with no retention interval (Group 1), decreasing ISI with 1 sec retention interval (Group 3) and decreasing ISI with 7.5 sec retention interval (Group 3). The results showed that decreasing ISI trial with 1 sec RI showed better performance on most serial positions (in terms of accuracy as well as response times) than both the other groups – decreasing ISI with no RI and decreasing ISI with 7.5 sec RI (Please see Appendix for detailed table).

6.4 Discussion

As explained in the Methods and Results sections, in this experiment, participants were divided into three groups. We will now examine the results of each of these groups separately and in combination to discuss the possible interpretations and how these results compare with previous studies.

6.4.1 Group 1 – Only Decreasing ISI

In this group, the results for the decreasing ISI schedule showed a good level of accuracy for all the 5 serial positions with the accuracy for serial positions 1-4 being very similar. The analysis of the results as well as the graph indicates that the serial position curve for this group was tending towards being flat; in other words, most of the serial positions were recognised equally. Serial position 5 was recognised more accurately than all the other serial positions. A study by Avons (1998) with non-verbal stimuli have shown similar serial position curves with little primacy effect and where the recency effect was restricted to the last item. The serial position curve in the present study, therefore, aligns well with the results found in his study. It also concurs with the idea that recognition of non-verbal stimuli without the need to remember the serial order of presentation of stimuli results in above average performance and this was explored by Ward et al (2007). There was a strong recency effect that was observed, and this could be due to the type of response measured. In these experiments, recognition was measured using a probe item presented at the end of the trial. The participant simply had to respond yes or no as to whether the probe items was part of the previous list or not. Lewandowsky, Nimmo & Brown (2008) indicated that, in the studies that measured recognition, there was a higher likelihood of observing recency effects for non-verbal stimuli.

6.4.2 Group 2 – Decreasing ISI and Increasing ISI

This group was crucial for observing the differences, if any, between the decreasing ISI and the increasing ISI condition. The reader may recall from the results section of this chapter, that a significant difference was seen between the decreasing ISI and increasing ISI condition with performance being better for the decreasing ISI condition. These results concur with our previous findings and indicate the beneficial effect of the decreasing ISI condition. Now, the study conducted by Welte & Laughery (1971) obtained conflicting results. They found that the increasing ISI schedule was better for recall. However, it is worth noting that their experiment utilised verbal memoranda and more crucially, their premise of the beneficial effects of increasing ISI schedule was based on the opportunity for rehearsal for items later in the sequence (due to larger temporal gaps). The reason for the present results could be indicative of the beneficial effect of the decreasing ISI schedule in a logarithmic manner. The compression of the psychological timeline is reversed and all the items in the list are equally and accurately remembered.

6.4.3 Group 3 – Decreasing ISI with alternating Retention Intervals

In this group, the varying retention intervals added an interesting new variable. The ratio rule (Brown et al., 2007) suggests that the log of the ratio of the ISI and the RI is proportional to the slope of recall. The third group (decreasing ISI with alternating retention intervals), the results indicated that having a short retention interval (1 sec) after list presentation increased the accuracy of response, whereas having a longer retention interval (7.5 sec) significantly reduced performance. This provides interesting data for interpretation of the processes of consolidation. It was thought in the discussion section of experiment 5, that a short RI increases the temporal isolation variable of the last item, resulting in better accuracy for the last item. Additionally, a short RI facilitated the consolidation of memory traces and led to more accurate responses, whereas a longer RI may have led to decay, possibly in the absence of any other processes like rehearsal or refreshing. Therefore, consolidation observed in this experiment may be independent of other processes like rehearsal or refreshing. If rehearsal or refreshing were employed, a longer RI should have led to better accuracy, but that is not the case. In this experiment, the benefit of temporal isolation due to increased inter item intervals was not as evident with a recency being observed for the last item.

6.4.4 Comparison between the decreasing ISI trials of Group 1 and Group 3

It interesting to note from the results that when overall accuracy of recall was compared between the decreasing ISI conditions with no RI, with 1 sec RI and with 7.5 sec RI, the decreasing ISI condition with 1 sec RI showed the best performance. In other words, a small retention interval is indeed beneficial than having no retention interval or having a retention interval that is too long. Now one suggestion is that when there is no retention interval, the recency effect is higher (as evidenced by a high accuracy for serial position 5) and there is no time for consolidation of the list as a whole. However, on the other hand, when the retention interval is too long, this leads to decay and items are lost. A short retention interval allows time for consolidation and therefore, leads to better recall. Other studies have also found similar results (Souza & Oberauer, 2014; Shipstead & Engles, 2013). Additionally, although Ricker (2015) in his review paper, described the literature for consolidation to be somewhat confusing, this present finding shows some evidence for the need for time to consolidate and that time may be somewhere between 1 sec and 7.5 for a short array of to-be-remembered items measuring immediate recognition memory.

Chapter 7 - The question of varying schedules for colour memory

7.1 Introduction to Experiment 6

This chapter examines the effects of temporal spacing within lists of visual items (colour squares. The previous experiments have found promising results indicating enhanced non-verbal memory for items that are more temporally isolated or have a larger temporal isolation variable. Now, arguably, colours can be verbalised, but we have used a number of colours from the colour wheel that are quite similar each other such that they are unlikely to be verbalised. Towards this end, this final experiment was designed to test the effects of varying temporal spacing schedules of presentation for colour memory. In this Experiment, the reader will see that the START and STOP device has been dropped as it was thought that it would interfere with encoding of colours if START and STOP were shown at the beginning and end of each trial. Instead, each trial consisted of six colour squares and as was done in previous experiments, the first and last items were dropped from the analysis. However, as the reader will see, this created a problem, in that there were only four serial positions finally available for analysis. The experiment tested two item lag conditions – equal ISI and decreasing ISI. As always, the key interest was the decreasing ISI condition.

In this experiment, it is predicted that colour memory would benefit from temporal isolation. Additionally, it will once again explore the effects of temporal isolation on serial recall or recognition, which was briefly explored for verbal memory in Experiment 1; however, in the present experiment, the stimuli are visual colour squares (unlikely that they might be verbalised). The varying schedules of the colour list will also determine if there is a beneficial effect of the decreasing ISI schedule of presentation as seen in some of the previous experiments in this record.

7.2 Methodology

7.2.1 *Participants.*

Twenty volunteers (8 males and 12 females) were recruited from the University of Leeds participant pool in exchange for course credits and from the University of Leeds Psychology Volunteer pool in exchange for payment. Their average age was 21.8 years, they had normal/corrected-to-normal vision and had not been diagnosed with a neurological problem.

7.2.2 *Stimuli.*

The experiment was programmed with MATLAB using the Psychophysics Toolbox extension (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997). The MATLAB program was based on the design of the experiments of Peterlandl and Oberauer (2018) who generously shared their program with us. This was then altered to suit the needs of the present experiment. Colour management settings were set to their default for the Windows 7 operating system.

7.2.3 Materials and Design.

The experiment was designed on MATLAB so as to record responses, to measure accurate response times and to get the exact colours. The colour squares were 2cm^2 in size and were presented on the centre of the screen for 1000ms one after the other with each colour square shifting from left to right. The first colour square of the trial was shown in the centre left of the screen and then each consecutive square shifted an equal distance to the right before the last colour square was shown in the centre right of the screen. Each trial consisted of 6 colour squares before they were presented with a colour-wheel on which they had to click to recreate the colours that they saw in the same order. There were 2 blocks of 120 such trials each. The Inter-stimulus interval (ISI) between individual words was manipulated to create only two item lag conditions - decreasing ISI with 3200, 1600, 800, 400, 200ms ISIs from the first to last colour square; equal ISI with 1240 ms ISIs from the first to last colour square. Participants were divided into two groups. They were allotted to groups alternatively. Eg Participant 1 in Group 1, Participant 2 in Group 2, Participant 3 in Group 1 and so forth. Group 1 had the equal ISI experimental condition first and; Group 2 was presented with decreasing ISI condition in the first session.

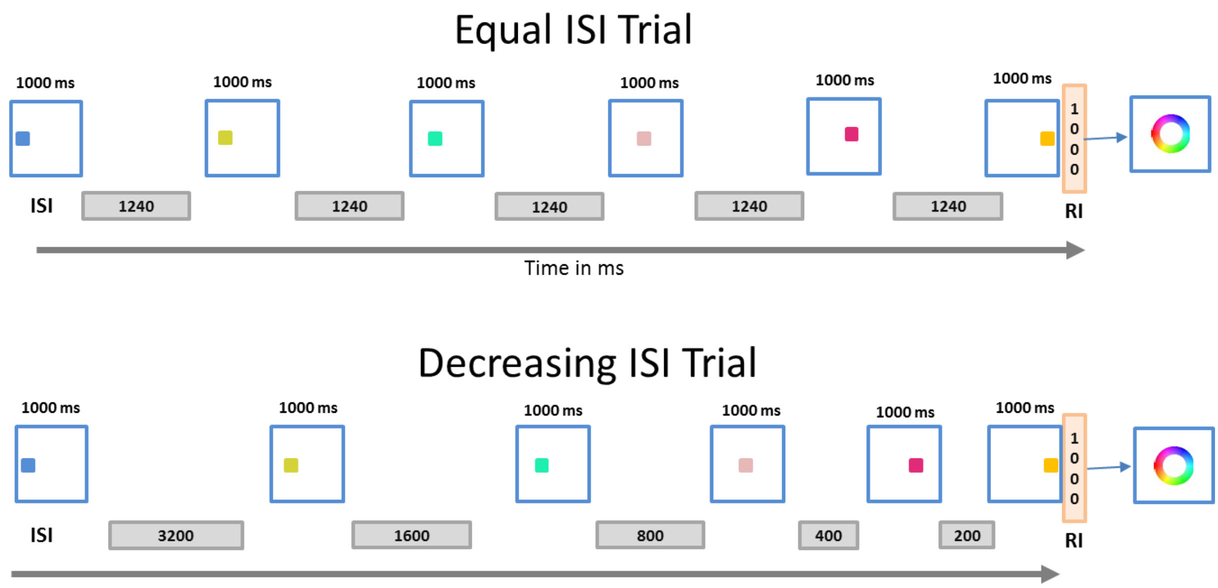

Figure 7.1 Different Inter Stimulus Intervals (ISI) in the two different item lag conditions (Decreasing ISI and Equal ISI) in Experiment 5

7.2.4 Procedure.

Participants completed a simple computer administered visual recall memory task consisting of 2 experimental blocks over 2 sessions and one practice block consisting of 4 trials at the beginning of each session. The 2 sessions are separated by at least 1 day.

In one session, the participants will complete 1 block consisting of 120 trials with 6 colours each. The colours were presented at the centre of the screen one after the other with each consecutive stimuli (colour square) shifting from left to right to prevent any masking effects. Each colour in the trial was shown for 1 second before disappearing. During the presentation of the trials, participants were also asked to continuously say ‘sasasasa’ to eliminate rehearsal of the colours. The participants’ voice was recorded every 16th trial to make sure that they continuously verbalise ‘sasasasa’. At the end of each trial, participants were presented with a colour-wheel at which point they identified the colours that they saw by recreating the order in which the colours were shown by clicking on different parts of the colour-wheel.

Unknown to the participants, the Inter-stimulus interval (ISI) between individual words was manipulated to create two item lag conditions - Decreasing ISI in session 1 and Equal ISI in session 2. Both sessions had a 1 second delay after the colours were presented, before participants were allowed to respond. Participants completed 240 trials (120 trials per item lag conditions). After every 10 blocks, the participants were given a break (minimum length of 2 minutes). Each experimental session consisted of 1 experimental block with 120 trials which lasted no longer than 60 minutes (including breaks) and they came for 2 such experimental sessions.

7.3 Results

The responses were recorded on MATLAB. The results from 2 participants were excluded from the analysis as they did not complete Session 2. Hence, the analysis was conducted for 18 participants (N = 18). The colours chosen by the participant on the colour-wheel after being presented with a list of 6 stimulus colours in each trial was the data collected. In other words, the data collected was accuracy of recall of colour for all the serial positions. The first and last serial positions were excluded from analysis as they did not conform to the temporal spacing schedule. Every colour on the colour-wheel was assigned a colour value ranging from 1 – 360. The error of each response was calculated as the absolute value of the difference between the stimulus colour value and the response colour value. This error needed to be corrected since the colour-wheel is round and the colour with the colour value 1 and 360 are actually next to each other and the difference between them is 1 rather than 359. Keeping this in mind, the error value was corrected using the formula

IF error > 180, then $error_{corrected}$ = 360 – error; IF error < 180, then $error_{corrected}$ = error.

Once we obtained the corrected error for each serial position, then the responses were recorded as correct if the error was within $\pm$ 1 SD for all the error values of the whole group for that particular serial position. For eg. If the stimulus colour value for serial position 1 in trial 1 was 270 and the response colour value was 5, then, first the error is calculated as the absolute value of the difference between 270 and 5; 270 – 5 = 265. The error was then corrected using the above formula. The error >180, so $error_{corrected}$ = 360 – 265 = 95. So the corrected error value is 95 and if this fell within $\pm$ 1 SD of all the corrected error values for serial position 1 for the whole group, then it was recorded as a correct response.

Fig. 7.2 shows the graph between the serial positions and the number of correct responses for each of the serial positions. Serial positions 1 and 6 were excluded as a TIV could not be calculated for these items.

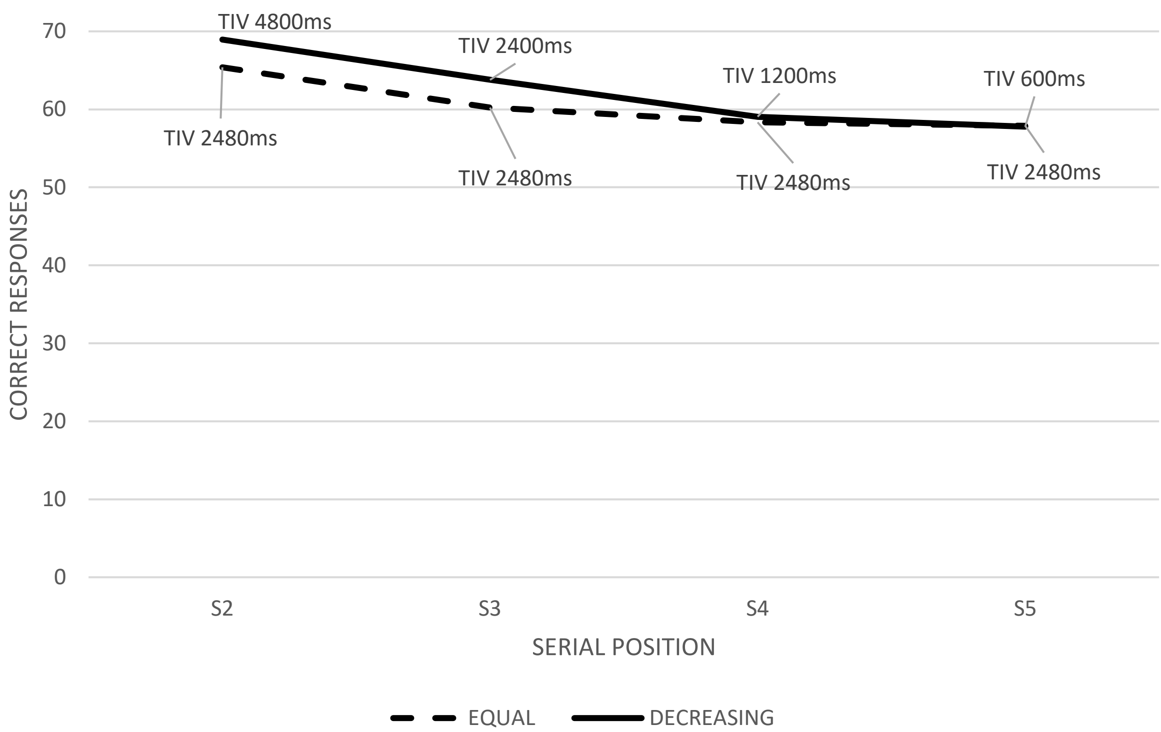

Figure 7.2 Number of correct responses for all serial positions (also showing TIV) for both item lag conditions (decreasing ISI and equal ISI)

The total number of possible correct responses were 120 for each serial position and it was seen that there is a good percentage of correct responses (> 50%) on the whole for both the item lag conditions (decreasing ISI an equal ISI). This experiment did not show much of a difference between the two item lag conditions (equal ISI and decreasing ISI) although there is a small difference between these two conditions for serial positions 2 and 3 with slightly higher accuracy for the decreasing ISI condition (not statistically significant).

Analysis of the results using a paired samples t test showed no significant differences between the two item lag conditions (equal and decreasing ISI) for any of the serial positions. A repeated measures ANOVA with the factors 2 x item lag conditions and 4 x serial position showed no effects of the different ISI conditions but revealed main effects of serial position on accuracy [$F(1, 17) = 31.031$, $p < 0.001$]. This also showed a medium effect size of 0.64. There was also no significant effect of the interaction between item lag condition and serial position.

7.4 Discussion

As noted in the Results section, a significant difference was not found between performance in the decreasing ISI condition as compared to the equal ISI condition. However, it was seen that a larger TIV or temporal isolation of the items led to better performance in identifying the order of the colours. This is concurrent with the results obtained by Souza & Oberauer (2014) where they demonstrated that, when a trial was taken as a whole, larger inter trial intervals (time between trials) enhanced performance. In other words, each trial was temporally distinct from the other when the inter trial intervals were longer. In the present study, the attention was on individual items within the list. Each colour was more or less temporally isolated from the other within a single list. As far as is known, previous studies have not examined this in detail. As previously explained, the present study has obtained some evidence for the benefits of temporal isolation for single stimuli (colour squares) within a list whereas until now, previous studies (Ecker, Tay et al., 2015; Oberauer & Lewandowsky, 2008; Souza & Oberauer, 2014) have only looked at the temporal isolation of each trial as a whole.

In terms of the lack of difference in performance between the decreasing ISI trial and the equal ISI trial, perhaps one explanation could be that the method of measurement of responses was different in this experiment. In this experiment, not only do the participants have to remember the colours but they also have to remember the order in which they were presented. This poses some difficulties and confounds as was discussed in previous experiments within this study (*see Experiment 1)* as well as previous studies which explored memory for serial order of non-verbal stimuli (Ward et al., 2007). In Experiment 1, the reader may recall that the serial recall condition did not show the beneficial effects of the decreasing ISI condition that was shown in the free recall condition. Therefore, when the participants do not have the additional burden of having to remember the serial order of the stimuli, they perform better and demonstrate the effects of the decreasing ISI logarithmic condition better. This additional burden may, in fact, have a greater effect on memory, thus reducing the observed effects of the ISI schedule conditions. This additional burden may be explained in terms of output interference where the later list items suffer more output interference. This is explained by the SIMPLE model (Brown et al., 2007). The SIMPLE model accounts for the negative effects of output interference. As the participant continues to recall the list items one by one, the list recedes more and more into the past, thus reducing the temporal distinctiveness of all the list items. Also, it is worth noting that when the participant knows that they have to recall the list in serial order, it is likely that they put less effort into encoding the later list items.

It is also interesting to note that the results of the present study are in agreement with previous studies that have examined memory for non-verbal stimuli. For instance, Peteranderl & Oberauer (2018) conducted a very similar study where they investigated the effects of serial position and temporal distinctiveness on serial recall of colours. They found strong primacy effects and almost no recency effects. They concluded that the reason could be the method of response measurement. On analysing previous literature, they found that the main difference between their study and previous studies which showed an opposite effect - strong recency effect and almost no primacy effect (Gorgoraptis et al., 2011; Kool et al., 2014) was that those studies measured recognition response of a probe item presented at the end and did not require the serial recall of the list items – as was required in their study. The same can be said for the present study as well. Although in the present study, one does not observe a prominent primacy effect in either the decreasing or equal ISI conditions, there is almost no recency effect.

Chapter 8 - General Discussion

8.1 Summary of Experiments

The main areas of research that are informing this study exist within the vast literature available on contemporary accounts of forgetting which are largely divided into decay and interference. It is impossible to complete a full review of this literature and therefore, an attempt has been made to outline and examine some of the key ideas within the vast literature of forgetting. The first area that the present study was interested in evaluating is the temporal or time based accounts of decay and forgetting. The contemporary accounts of temporal isolation were discussed with the aim of better understanding the processes of encoding and retrieval and those that lead to forgetting. The other group of studies which also lies within forgetting literature is serial position curves. Again, it has to be noted that reviewing all the research conducted on serial position curves is beyond the scope of the present thesis. Therefore, the present study only outlined the literature that is most relevant. This discussion will briefly describe the design of each of the experiments and their results will be summarised. It will then attempt to set these findings against previous research to better understand and interpret these results within the context of the larger area of research. It will also attempt to provide some recommendations for future research.

Experiment 1 set out to explore the effects of varying temporal intervals between stimuli. A few other studies had attempted this, but the main difference was the temporal schedules of the lists of stimuli. In Experiment 1, a key interest was to examine the concept of compressed psychological memory for list memory by manipulating the temporal schedules of presentation in a logarithmic manner such that the inter item intervals keep increasing or decreasing as the list progresses. The time interval between successive items – in the present experiment the stimuli were verbal in nature (the reader may recall that the conditions were labelled increasing ISI, decreasing ISI and fixed irregular ISI schedule). Two methods of measuring performance were utilised – free recall condition and serial recall condition. Performance in a sample of young adults on the task was illuminating and provided evidence for the beneficial effect of temporal isolation of items. A new construct called the temporal isolation variable was introduced which is the sum of the distances in milliseconds of an item from its immediate neighbours. The items that had a higher temporal isolation variable were recalled better in both free and serial recall conditions. There was a better performance in the decreasing ISI trials where performance was measured by free recall and although serial recall conditions did not show a better performance overall for the decreasing ISI schedule, they also provided strong evidence for temporal isolation. It was thought in discussion of that experiment that this could be providing preliminary evidence for the beneficial effect of the decreasing ISI condition on memory performance and a potential was seen for further exploration.

Experiment 2 utilised a similar design except, instead of the fixed irregular ISI control condition, an equal ISI condition was used as the control. This experiment also was interested in exploring the different factors such as rehearsal and refreshing in the consolidation and eventual recall of the list items. Therefore, by reducing opportunities for rehearsal and refreshing, the effect of temporal isolation and the temporal spacing (logarithmic) schedule was examined more in depth. This was achieved by inserting different tasks to minimise rehearsal and refreshing within the inter item intervals. The basic design was kept constant and there were two groups – one group was controlled for articulatory rehearsal and one group was controlled for attentional refreshing. Each of the groups also had control conditions where rehearsal and refreshing were allowed. Performance of another group of young adults in this experiment revealed a similar result to Experiment 1. Positive effects of temporal isolation were seen on the recall of items with higher temporal isolation variable and although controlling for rehearsal and refreshing resulted in the overall reduction of performance, there was evidence to suggest that even with interference or distractors during the inter-item intervals, items that have a higher TIV were recalled better. The serial position curve in this experiment was again tending towards a flatter curve than the usual dipped curve in the decreasing ISI condition. This suggests that although processes like rehearsal and refreshing occur during the time intervals and facilitate better performance, a higher temporal isolation on its own also has a beneficial effect on recall.

Experiment 3 set out to reduce the effects of yet another possible confounding factor – proactive interference. This was achieved by reducing the number of trials to two trials per participant; thereby reducing proactive interference from the stimuli of numerous previous trials commonly seen in multi-trial experiments. Instead, the sample size was increased in order to obtain a reliable normative data set with a small number of trials in the experiment. A larger group of young people (N = 124) recruited and shown a decreasing ISI trial and an equal ISI trial each containing lists of verbal stimuli. Here, the results were more unequivocal and showed that performance was significantly better for the decreasing ISI trial. Moreover, the serial position curve for the decreasing ISI trial revealed a flatter curve as compared to the equal ISI trial which showed the typical dipped serial position curve. The beneficial effects of a higher TIV for the different items in the list were also seen. It was discussed that reducing proactive interference while allowing for rehearsal and/ or refreshing during inter item intervals enhanced beneficial effect of the decreasing ISI condition as compared to the equal ISI condition, thus providing some evidence for the concept of reversing the distortion or compression in psychological memory.

In Experiment 4, the benefit of a higher temporal isolation variable and the decreasing spacing schedule of presentation of lists on task performance was examined further by changing the nature of the stimuli. This experiment was designed to explore whether similar results were seen in non-verbal stimuli. Here, non-verbal stimuli (Chinese symbols) were used instead of verbal stimuli and a similar design to that of the previous experiment was employed in that the number of trials were minimised to reduce proactive interference; however, a between subjects design was utilised, and recognition was used as the response measure rather than recall. This experiment also measured the ‘strength of the memory trace’ by measuring the response time and measured the accuracy of correctly identifying the position of a positive probe within the list, essentially requiring the subjects to not only remember the stimuli but also remembering their position within the list of items. A larger sample (N = 62) was recruited, and they were divided into two groups where one group was shown only the decreasing ISI condition and the other group was exposed to the control equal ISI condition. The results from this experiment were less promising with a ceiling effect observed for one particular serial position which confounded some of the results. Although, an analysis attempted by removing the confounding data point showed that the serial position curve for the decreasing ISI condition was flatter than the equal ISI condition, the results have to be interpreted with caution. The overall performance also did not differ between the two different conditions. However, apart from the confounding data variable, the results showed evidence for the benefit of a higher temporal isolation variable for recognition of the stimuli, both in terms of the accuracy as well as the response time. This indicates that the accuracy and strength of the memory trace was higher for the items that had a higher temporal isolation variable. In terms of correctly identifying the position of an item within the list as well as the response time for that, there was no significant difference between the two conditions although the positions of the items with higher TIV was identified more accurately than others on average.

In Experiment 5, the benefit of the inter-item interval on task performance was examined further by manipulating the opportunity to engage in short-term memory trace consolidation. A new sample of younger adults (N = 51) were divided into three groups; one group was exposed only to the decreasing ISI condition; the second group were exposed to increasing ISI condition and decreasing ISI condition and a third group were shown decreasing ISI trials with alternating retention intervals. The design of the experiment was very similar to the previous experiment with the small modification of a larger number of trials with more data points for each serial position. The results from the first group (only decreasing ISI condition) showed a serial position curve tending towards being flat with equal probability of recognition for all the serial positions except the last one. The response time data also showed a similar result. The beneficial effect of higher TIV was also seen in task performance. When it came to the second group (decreasing and increasing ISI condition), a similar benefit of higher TIV was seen but more interesting was the benefit of the decreasing ISI schedule over the increasing ISI schedule which was, however, not fully reflected in the response times. The third group (decreasing ISI with alternating retention intervals), the results indicated that having a short retention interval (1 sec) after list presentation increased the accuracy of response, whereas having a longer retention interval (7.5 sec) significantly reduced performance. This provides interesting data for interpretation of the processes of consolidation. It was thought in the discussion section of experiment 5, that a short RI increases the temporal isolation variable of the last item, resulting in better accuracy for the last item. Additionally, a short RI facilitated the consolidation of memory traces and led to more accurate responses, whereas a longer RI may have led to decay, possibly in the absence of any other processes like rehearsal or refreshing. Therefore, it was argued that consolidation observed in this experiment is independent of other processes like rehearsal or refreshing. If rehearsal or refreshing were employed, a longer RI should have led to better accuracy, but that is not the case. In this experiment, the benefit of temporal isolation due to increased inter item intervals was not as evident with a recency being observed for the last item.

Experiment 6 went a step further in the exploration of temporal spacing schedules for non-verbal memoranda. Instead of utilising non-verbal characters as in the previous experiment, experiment 6 examined memory for colours. Here, the experiment was designed using MATLAB and trials of 6 colour squares was presented with 2 ISI conditions – decreasing ISI and equal ISI. Following the presentation of each trial, participants were presented with a colour wheel where they had to choose the colours in the order that they were seen. The results of this experiment did not reveal a significantly better performance for the decreasing ISI condition but revealed a slight beneficial effect of temporal isolation in memory for colours with more accurate recall for serial position 2 and 3 as compared to the later serial positions of

3 and 4. The results of this experiment leave further questions to be answered which are beyond the scope of the present study but may be worth exploring and are detailed in the suggestions for future research section of this chapter.

As a starting point, this chapter discusses if the study has managed to answer the questions asked at the outset and if yes, how well this has been achieved.

(a) whether in fact there is evidence for temporal isolation benefitting memory,

(b) would the application of an optimal spacing schedule for a serially ordered list maximise recall and render the serial position curve flat and if so,

(c) what is that optimal spacing schedule to reverse the distortion in memory.

8.2 Evidence for temporal isolation benefitting memory

8.2.1 Verbal Memory

Temporal isolation or temporal distinctiveness is the extent to which a given stimulus 'stands out' from other stimuli temporally (Sikstrom, 2006). According to temporal distinctiveness models, items that are temporally isolated from their neighbours are more distinct and thus will be remembered better. As the reader may recall, in the Introduction, studies were reviewed which suggested that larger temporal isolation benefits recall (Neath & Crowder, 1996; Welte & Laughery, 1971; Bjork & Whitten, 1974; Glenberg & Swanson, 1986). Ronnberg (1980) found that the probability of recall for temporally crowded items were poor (see also Ronnberg, 1981). As discussed in the Introduction, Brown et al. (2006) presented subjects with lists of verbal stimuli where the items were separated by varying temporal gaps filled with different number of digits depending on the duration of the gaps. They found a strong temporal isolation effect, with recall improving by almost 5–10% for each additional second of isolation. These findings were in line with the expectations of temporal distinctiveness theories, and they proposed that temporal isolation effects are seen more or less depending on the method of recall (serial or free recall).

The present series of experiments (almost all the Experiments in some form or the other) also provide clear evidence for temporal isolation benefitting memory (specifically *free recall),* not only for verbal stimuli, but also for non-verbal stimuli. Whether there are active processes involved during the larger inter-item intervals or whether the mere existence of a temporal isolation between the items in a list lead to better performance due to reduced temporal crowding is something that needs to be discussed further. When it came to serial recall, the only two experiments that measured serial recall were Experiment 1 (using verbal stimuli) and Experiment 6 (using colours). In both these experiments, the effect of temporal isolation was not observed greatly. This is in concordance with previous studies that have obtained similar results (Lewandowsky et al., 2006; Nimmo & Lewandowsky, 2005, 2006) not only with verbal stimuli but also with auditory spatial stimuli (Parmentier, King & Dennis, 2006). The studies that have shown isolation effects have used free recall (e.g., Brown et al., 2006) whereas all studies in which an isolation effect was minimal or absent have used serial recall.

8.2.2 Non-verbal memory

As we discussed in the Introduction (*see section 1.3.2*), there is evidence supporting temporal distinctiveness when applied to visual memory performance (e.g. Guérard, Neath, Surprenant, & Tremblay, 2010; Shipstead & Engles, 2013; Souza & Oberauer, 2015). Shipstead and Engles (2013) found that when they varied both the retention interval (RI) and the inter-trial interval (ITI). A longer RI resulted in compression of the interval between the current trial and the preceding trial due to logarithmic compression of psychological time. Therefore, they observed that when the RI is longer, this leads to increased confusability. In our Experiments 4, 5 and 6 with non-verbal stimuli, we did not vary the inter trial intervals but in Experiment 5, we varied retention intervals which showed temporal distinctiveness effects with poorer recall when the RI was higher; in other words, when the time to recall was longer. Although temporal distinctiveness theories as well as decay theories predict that a longer separation between time of encoding and time of retrieval (retention interval) reduces the possibility of the encoded item to be remembered, their main difference is the role of relative time. Temporal distinctiveness theories predict that the temporal isolation of an encoded item relative to its neighbours will improve memory, but the decay theories make no prediction regarding relative time. These findings were extended by Souza and Oberauer (2014) (*see Introduction Section 1.3.2*) who varied the distinctiveness of memory items by manipulating the ratio between the retention interval and the inter-trial interval. They observed that performance was best for a relatively short retention interval and a long inter-trial interval, rendering each trial temporally distinct. In the present series of experiments, Experiment 6 used a colour recall task but instead of recognition, the study measured serial recall of all the colours presented in the list and temporal distinctiveness of each stimulus colour within a list was examined. Mild benefits were found for more temporally isolated stimuli within the list.

SIMPLE (Scale Invariant Memory, Perception, and LEarning) model of Brown, Neath, and Chater (2002) predicts a beneficial effect of temporal separation on memory. Based on the logarithmic compression in psychological memory timeline explained by Crowder (1976) – *see Introduction section 1.3.2.,* the SIMPLE model predicts an advantage for recent items over temporally distant events. SIMPLE also allows for the fact that that memory traces are likely to be multi-dimensional and may involve variables in addition to time; most important of which in the present context is the grouping structure of the list (Lewandowsky, Brown, Wright, & Nimmo, 2006; Lewandowsky, Duncan, & Brown, 2004). It is primarily the separation of items from each other temporally that determines retrieval in terms of recall or recognition, such that larger separation between items enables more accurate recall than items that are crowded close together. In the present series of experiments, temporal isolation is found to be beneficial as stated before but in Experiment 4, the retention intervals were also manipulated along with the inter stimulus intervals. The results of this experiment showed that longer retention intervals (longer than 7 sec) were not beneficial for memory. One of the explanations for these findings could be accounted for by the SIMPLE model. The time to retrieval is longer and hence performance may be reduced due to proactive interference from previous lists.

Another interesting area of discussion is what are the processes if any, that occur during the temporal space between stimuli that enhances the memory for them? Now, time-based accounts as stated earlier, believe in the innate nature of temporal isolation leading to better encoding and thus consolidation of the memory trace. It is interesting to note that although Baddeley & Hitch's (1974) working memory model primarily focused on the maintenance of verbal information using rehearsal, the concept of working memory itself assumes that if a memory trace is not encoded well in the first place, it is likely to be lost. Thus, paying attention to the stimuli or memory trace requires time and this enhances memory for it later. If the memory trace is confused with others during presentation or if they are too temporally crowded, it is likely that they are not even encoded well to begin with. However, it is also important to consider active processes such as rehearsal or refreshing occurring during the unfilled time gaps between items. In the present study, Experiment 2 controlled for rehearsal and refreshing and the results indicated a reduced performance overall although in most trials, temporal isolation still benefitted memory. This is in line with the findings of previous studies (Baddeley, 1975; Camos et al., 2009). This leads to an interesting discussion about memory consolidation and whether it is an active process involving rehearsal and refreshing or whether it is a passive process that just occurs due to reduced confusability and vulnerability of items to be lost due to neighbouring stimuli. This is discussed further in section 8.6

8.3 A spacing schedule for a serially ordered list to maximise recall

The second question while embarking on this journey was whether there exists an optimal spacing schedule to reverse the distortion or compression in the temporal record of past memory. The Welte & Laughery study in 1971, was one of the first studies to consider varying the presentation schedules for a verbal list of stimuli. Here they employed an arithmetic progression for the temporal spacings between the stimuli. They found that increasing ISI condition was better in the later positions which is replicated in some of the experiments in the present study as well. However, they also found that in the free recall condition, performance was far better for the decreasing ISI condition. Another study by Neath & Crowder in 1990 used increasing and decreasing presentation schedules. They added varying amounts of distractor activity between the stimuli. By systematically increasing or decreasing the distractor activity, they created temporal isolation between the stimuli as well as the increasing and decreasing ISI schedules. In this study as well, the results showed a higher frequency of recall for the decreasing ISI schedule. The proposed beneficial effect of the decreasing ISI schedule, although has its roots in Crowder's (1976) telephone pole analogy, is a relatively new concept and therefore there are not many studies which have tried to explore this area. In the present series of experiments, one would venture to state that a good starting point for the spacing schedule has been established. The spacing schedules employed in these experiments are log to the base of 2 and they have shown promising results. Most of the experiments (Experiment 1, Experiment 2, Experiment 3, Experiment 4 and Experiment 5) in the present series showed some beneficial effect of the decreasing ISI condition though not always resulting in better overall performance.

Therefore, these experiments have paved a way and indicates that the research is going in the right direction with the decreasing ISI condition and the logarithmic spacing although it seems to work better for free recall or recognition of verbal and non-verbal stimuli other than colour; it does not work as well for serial recall – as seen in Experiment 1 and Experiment 6.

8.4 Is the serial position curve flat?

The third question at the outset was whether the decreasing ISI condition can potentially reverse the distortion in memory and essentially render the serial position curve flat. In the present series, the results indicate that the serial position curve is not completely flat but it is indeed interesting to note the trend line for the decreasing ISI curve as the experiments progress. There is an increasing probability of all the serial positions being remembered equally in the decreasing ISI condition. Specifically, a tendency for a flatter decreasing ISI serial position curve was seen in Experiment 1, Experiment 3 and Experiment 5. The serial position curve was initially demonstrated by Murdock (1962) where he described the 'dipped' serial position curve with primacy and recency effects (*See Introduction Section 1.3.1*). This phenomenon was later replicated by many studies and not only seen for a verbal list but also for visual-spatial movements, visual-spatial locations, auditory-spatial locations etc. (Hurlstone et al., 2014; Smyth and Scholey, 1996; Avons, 2007; Agam et al., 2010). Serial recall is the recall of a list of items in the same order that it was presented. The serial position effect was seen in this paradigm as well (Jones et al., 1992; Jones and Oberauer, 2013; Baddeley and Hitch, 1974), although admittedly, the bow is not as pronounced, with a slight increase in primacy and a decrease in recency (Page and Norris, 1998). Studies for non-verbal memory of items reveal serial position curves that are slightly different. The recency effect was restricted to the last item and almost no noticeable primacy effect was seen (Broadbent and Broadbent, 1981; Christie and Phillips, 1979; Hines, 1975). In the present series of experiments, the dipped serial position curve is not seen much apart from in control equal ISI conditions. Although some primacy and recency effects were seen to varying degrees, the decreasing ISI curve tended towards becoming flatter as the experiments progressed as the confounding variables were reduced. It is worth exploring this further in future studies.

8.5 Temporal spacing and decay

As noted in the Introduction (*section 1.2.2)*, decay theories of forgetting have been explored for a long time. Brown's initial study in 1958 piqued the interest of memory theorists at the time and led to further exploration of time-based decay as a cause of forgetting. In the present series of experiments, Experiment 2 found evidence for decay theories as suggested by Baddeley & Scott (1976) in their working memory model as well as the TBRS model which assumed decay to be implicit *(see section 1.2.2).* They argued that decay is bound to occur if process such as rehearsal and refreshing are prevented. Sure enough, in Experiment 2, poorer performance was seen for trials that prevented rehearsal and refreshing using distractors.

8.6 Memory consolidation and temporal spacing

Short-term memory is also influenced and indeed enhanced by the time allowed for consolidation (Bayliss, Bogdanovs, & Jarrold, 2015; Jolicœur & Dell'Acqua, 1998). Essentially, most literature describes consolidation that occurs, when given time (possibly includes time for active processes such as rehearsal and refreshing) and in the absence of interference. During an unfilled time interval (with no interference), memory consolidation may occur by utilising aforementioned strategies like rehearsal and refreshing. Therefore, it may be seen as active process assists in enhancing memory (Dewar et al., 2014; Mercer, 2015). If these processes are active, it is only logical that sufficient time must be given for this process to take place. The forgetting law of Jost (end of the 19th century) suggested that as time passes, old items within memory become less vulnerable to the disruptive effects of subsequent events: in other words, they show a reduced vulnerability to decay despite the lapse of time and the presence of successive interference. Intuitively, this idea that retroactive interference can be reduced by allowing for a temporal interval for the encoded memory trace to ‘sink in’ is not only compelling, but also has empirical support. However, as discussed in the Introduction (*section 1.2.3*), it is not wholly clear how consolidation plays a role in memory and how much time is needed for effective consolidation to occur. In Experiment 4, it was found that when the retention intervals were non-existent, consolidation did not occur and when retention intervals were long (7.5 sec), it led to loss of memory traces. Performance was best when the retention intervals existed for consolidation but were kept relatively short (1 sec). Therefore, it can be assumed that for a short array of to-be-remembered items, time required for consolidation is somewhere between 1 and 7.5 sec.

From the above discussion, it is clear that concepts of interference as well as temporal decay continue to hold an enduring appeal in accounts of forgetting over the short term and the essential role they play in memory consolidation.

In the present series of experiments, Experiment 2 and Experiment 6 provides preliminary evidence that temporal isolation between successive items may be sufficient in itself to enhance memory for an item (despite introducing distractors to prevent rehearsal and refreshing). This may be explained by the concept of temporal discriminability or confusability. Even though there was limited opportunity for active maintenance processes, the simple fact that there was a larger temporal gap between two items led to reduced confusability of each item, thereby leading to better recall. Other studies (Ecker, Tay et al., 2015; Mercer, 2014) have found evidence that increasing inter stimulus interval may lead to reduced confusability. Although, the evidence obtained in the present study is minimal, it may be an area worth exploring to better understand the processes of consolidation.

8.7 Suggestion for future research

8.7.1 Logarithmic spacing schedule

Mental time is believed to be logarithmic (Brown et al., 2007). The current report considered a given logarithmic spacing schedule (for ease of implementation). In the present series, log to the base of two was explored. The spacing schedules in to be remembered lists were fairly short (to the tune of seconds through to a few minutes) as this series was primarily interested in immediate memory. Future research could consider varying the logarithmic spacing schedules and add to the present data to propose a spacing schedule that may be successful in reversing the distortion in memory record. There is also scope for changing the logarithmic spacing to be larger and look at not just immediate memory but memory over the long term. There is a recent study which explores the serial position effects of words presented over very long intervals, but it might be interesting to explore the same using long intervals arranged logarithmically.

8.7.2 Nature of stimuli utilised

Although the present series has examined verbal and non-verbal stimuli, a more in-depth exploration of the different types of stimuli could be carried out. For instance, memory for spatial stimuli or auditory stimuli would be interesting to explore and find out whether they adhere to the distortions in temporal memory record and whether they can be reversed using similar spacing schedules.

8.7.3 Clinical applications

In the Calgary-Cambridge observation guide to the medical interview, one of the key characteristics of communicating effectively within a medical interview is explanation and planning to aid understanding and effective recall of information (eg. Remembering instructions about medication taking). The current methods to aid recall suggested in the guide are chunking, rehearsal etc. which are no doubt effective but can be improved upon.

According to our results, free recall of verbal information is enhanced when items to be recalled are spaced temporally in a logarithmically decreasing schedule, termed negatively compressed. Future research could certainly look towards implementing this in a clinical interview setting. For instance, 'Temporal spacing of therapeutic instructions' (TSTIs) maintaining optimal inter-item spacing through a session lasting perhaps 20 minutes. The predictions would be that this should aid in better recall of information presented during the medical interview leading to better compliance to medication, possibly fewer relapses and an overall increase in health and well-being.

8.8 Conclusion

In conclusion, the present study has provided plenty of evidence for the beneficial effect of temporal isolation in memory for lists (verbal and non-verbal memoranda) where a higher temporal isolation variable usually leads to better recall. The present series of experiments have also attempted to study the temporal distortion in immediate memory record. In doing so, these experiments have shown that in free recall, for verbal and (some) non-verbal memory, the decreasing ISI schedule of presentation of stimuli may be beneficial. At the same time, no such beneficial effect has been found for serial recall. The serial position curve tends not to show the popular dipped shape when inter stimulus intervals are manipulated to be varying (increasing ISI or decreasing ISI), rather than equal. In some experiments, the present study also found that when the stimuli are presented in a decreasing ISI schedule, the serial position curve tends towards being flatter, in other words, with a higher probability of all the items in a list being remembered equally.

Chapter 9 - References

Agam, Y., Huang, J., & Sekuler, R. (2010). Neural correlates of sequence encoding in visuomotor learning. Journal of neurophysiology, 103(3), 1418–1424. https://doi.org/10.1152/jn.00662.2009

Altmann, E. M., & Gray, W. D. (2002). Forgetting to remember: The functional relationship of decay and interference. Psychological Science, 13(1), 27-33. doi: 10.1111/1467-9280.00405

Altmann, E. M., & Schunn, C. D. (2012). Decay versus interference: a new look at an old interaction. Psychological Science, 23(11), 1435-1437. doi: 10.1177/0956797612446027

Altmann, E. M., & Trafton, J. G. (2002). Memory for goals: An activation-based model. Cognitive Science, 26(1), 39–83. https://doi.org/10.1207/s15516709cog2601_2

Atkinson, R.C. and Shiffrin, R.M. 1968. Human memory: A proposed system and its control processes. *Psychology of learning and motivation.* **2**, pp.89-195.

Avons, S.E. 1998. Serial report and item recognition of novel visual patterns. *British journal of psychology (London, England : 1953).* **89 (Pt 2)**(2), pp.285-308.

Avons, S.E. 2007. Spatial span under translation: A study of reference frames. *Memory & Cognition.* **35**(3), pp.402-417.

Baddeley, A., & Scott, D. (1971). Short term forgetting in the absence of proactive interference. Quarterly Journal of Experimental Psychology, 23, 275-283.

Baddeley, A. 1986. *Oxford psychology series, No. 11. Working memory*. New York: Clarendon Press/Oxford University Press.

Baddeley, A. 2000. The episodic buffer: a new component of working memory? *Trends in cognitive sciences.* **4**(11), pp.417-423.

Baddeley, A. (1992). Working memory. Science, 255(5044), 556-559.

Baddeley, A.D. & Hitch, G. 1974. Working Memory. In: Gordon, H.B. ed. *Psychology of Learning and Motivation.* Academic Press, pp.47-89.

Baddeley, A. D., Thomson, N., & Buchanan, M. (1975). Word length and the structure of short-term memory. Journal of verbal learning and verbal behavior, 14(6), 575-589.

Barrouillet, P., & Camos, V. (2002). Savoirs, savoir-faire arithmétiques, et leurs deficiencies. Paris: Rapportpour le Ministère de la Recherche.

Barrouillet, P., Bernardin, S., & Camos, V. (2004). Time constraints and resource sharing in adults' working memory spans. Journal of Experimental Psychology: General, 133, 83–100.

Barrouillet, P., Bernardin, S., Portrat, S., Vergauwe, E., & Camos, V. (2007). Time and cognitive load in working memory. Journal of Experimental Psychology: Learning, Memory, and Cognition, 33, 570–585.

Barrouillet, P., De Paepe, A., & Langerock, N. (2012). Time causes forgetting from working memory. Psychonomic Bulletin & Review, 19, 87–92. Bhatarah, P. et al. 2009. Examining the relationship between free recall and immediate serial recall: Similar patterns of rehearsal and similar effects of word length, presentation rate, and articulatory suppression. *Memory & Cognition.* **37**(5), pp.689-713.

Bayliss, D. M., Bogdanovs, J., & Jarrold, C. (2015). Consolidating working memory: Distinguishing the effects of consolidation, rehearsal and attentional refreshing in a working memory span task. Journal of Memory and Language, 81, 34-50. doi: 10.1016/j.jml.2014.12.004

Beaudry, O., Neath, I., Surprenant, A. M., & Tehan, G. (2014). The focus of attention is similar to other memory systems rather than uniquely different. Frontiers in Human Neuroscience, 8, Article 56.

Berman, M. G., Jonides, J., & Lewis, R. L. (2009). In search of decay in verbal short-term memory. Journal of Experimental Psychology: Learning, Memory, and Cognition, 35(2), 317-333. doi: 10.1037/a0014873

Bjork, R.A. and Whitten, W.B. 1974. Recency-sensitive retrieval processes in long-term free recall. *Cognitive Psychology.* **6**(2), pp.173-189. doi: 10.1016/0010-0285(74)90009-7

Broadbent, D (1958). Perception and Communication. London: Pergamon Press.

Broadbent, D.E. and Broadbent, M.H.P. 1981. Recency effects in visual memory. *The Quarterly Journal of Experimental Psychology Section A.* **33**(1), pp.1-15.

Brown, J. (1958). Some tests of the decay theory of immediate memory. The Quarterly Journal of Experimental Psychology, 10, 12–21. doi:10.1080/17470215808416249.

Brown, G. D., & Lewandowsky, S. (2010). Forgetting in memory models. In S. Della Sala (Eds.), Forgetting (pp. 49-75). Hove: Psychology Press.

Brown, G. D., Neath, I., & Chater, N. (2007). A temporal ratio model of memory. Psychological Review, 114(3), 539-576. doi: 10.1037/0033-295X.114.3.539

Brown, G. D., Morin, C., & Lewandowsky, S. (2006). Evidence for time-based models of free recall. Psychonomic bulletin & review, 13(4), 717-723.

Brown, G. D., Vousden, J. I., & McCormack, T. (2009). Memory retrieval as temporal discrimination. Journal of Memory and Language, 60(1), 194-208.

Burgess, N., & Hitch, G. J. (1999). Memory for serial order: A network model of the phonological loop and its timing. Psychological review, 106(3), 551.

Camos, V., Lagner, P., & Barrouillet, P. (2009). Two maintenance mechanisms of verbal information in working memory. Journal of Memory and Language, 61(3), 457-469.

Camos, V., Mora, G., & Oberauer, K. (2011). Adaptive choice between articulatory rehearsal and attentional refreshing in verbal working memory. Memory & Cognition, 39(2), 231-244.

Christie, D.F.M. and Phillips, W.A. 1979. Simple drawing and pattern completion techniques for studying visualization and long-term visual knowledge. *Memory & Cognition.* **7**(5), pp.360-367.

Corballis, M.C. 1966. Memory span as a function of variable presentation speeds and stimulus durations. *J Exp Psychol.* **71**(3), pp.461-5.

Corballis, M.C. and Loveless, T. 1967. The effect of input modality on short-term serial recall. *Psychonomic Science.* **7**(8), pp.275-276.

Cowan, N. (2011). The focus of attention as observed in visual working memory tasks: Making sense of competing claims. Neuropsychologia, 49(6), 1401-1406. doi: 10.1016/j.neuropsychologia.2011.01.035

Cowan, N., Saults, J. S., & Nugent, L. D. (1997). The role of absolute and relative amounts of time in forgetting within immediate memory: The case of tone-pitch comparisons. Psychonomic Bulletin & Review, 4(3), 393-397. doi:10.3758/BF03210799

Craik, F.I. and Lockhart, R.S. 1972. Levels of processing: A framework for memory research. *Journal of verbal learning and verbal behavior.* **11**(6), pp.671-684.

Crowder, R.G. 1976. *Principles of learning and memory.* Lawrence Erlbaum Associates.

Daneman, M.; Carpenter, P. A. (1980). "Individual differences in working memory and reading". Journal of Verbal Learning and Verbal Behavior. 19 (4): 450–466.

Dewar M, Alber J, Cowan N, & Della Sala, S. (2014) Boosting long-term memory via wakeful rest: intentional rehearsal is not necessary, consolidation is sufficient. PLoS ONE 9(10), e109542. doi: 10.1371/journal.pone.0109542

Ebbinghaus, H. (1885). Uber das Gedachtnis. Leipzig: Duncker & Humblot.

Ecker, U. K., Brown, G. D., & Lewandowsky, S. (2015). Memory without consolidation: Temporal distinctiveness explains retroactive interference. Cognitive science, 39(7), 1570-1593. doi: 10.1111/cogs.12214

Ecker, U. K., & Lewandowsky, S. (2012). Computational constraints in cognitive theories of forgetting. Frontiers in Psychology, 3(400), 1-5. doi: 10.3389/fpsyg.2012.00400

Ecker, U. K., Lewandowsky, S., & Oberauer, K. (2014). Removal of information from working memory: A specific updating process. Journal of Memory and Language, 74, 77-90. doi: 10.1016/j.jml.2013.09.003

Ecker, U. K., Tay, J. X., & Brown, G. D. (2015). Effects of prestudy and poststudy rest on memory: Support for temporal interference accounts of forgetting. Psychonomic Bulletin & Review, 22(3), 772-778. doi: 10.3758/s13423-014-0737-8

Farrell, S. and Lewandowsky, S. 2002. An endogenous distributed model of ordering in serial recall. *Psychonomic Bulletin & Review.* **9**(1), pp.59-79.

Farrell, S., Oberauer, K., Greaves, M., Pasiecznik, K., Lewandowsky, S., & Jarrold, C. (2016). A test of interference versus decay in working memory: Varying distraction within lists in a complex span task. Journal of Memory and Language, 90, 66-87. doi: 10.1016/j.jml.2016.03.010

Geiger, S.M. and Lewandowsky, S. 2008. Temporal isolation does not facilitate forward serial recall—or does it? *Memory & Cognition.* **36**(5), pp.957-967.

Glenberg, A. M., Bradley, M. M., Kraus, T. A., & Renzaglia, G. J. (1983). Studies of the long-term recency effect: Support for a contextually guided retrieval hypothesis. Journal of Experimental Psychology: Learning, Memory, and Cognition, 9(2), 231-255. doi: 10.1037/0278-7393.9.2.231

Glenberg, A.M. and Swanson, N.G. 1986. A temporal distinctiveness theory of recency and modality effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition.* **12**(1), pp.3-15.

Grange, J. A., & Cross, E. (2015). Can time-based decay explain temporal distinctiveness effects in task switching? The Quarterly Journal of Experimental Psychology, 68(1), 19-45. doi:10.1080/17470218.2014.934696

Grenfell-Essam, R., Ward, G., & Mack, C. (2019). Temporal isolation effects in immediate recall. Journal Of Memory And Language, 109.

Gorgoraptis N, Catalao RFG, Bays PM, Husain M. Dynamic Updating of Working Memory Resources for Visual Objects. The Journal of Neuroscience. 2011;31:8502–8511.

Guérard, K., Neath, I., Surprenant, A. M., & Tremblay, S. (2010). Distinctiveness in serial memory for spatial information. Memory & Cognition, 38(1), 83-91. doi: 10.3758/MC.38.1.83

Harris J.D, (1952). The decline of pitch discrimination with time. Journal of Experimental Psychology. 43, 96-99.

Hardt, O., Nader, K., & Nadel, L. (2013). Decay happens: the role of active forgetting in memory. Trends in Cognitive Sciences, 17(3), 111-120. doi: 10.1016/j.tics.2013.01.001

Henson, R.N.A. 1998. Short-Term Memory for Serial Order: The Start-End Model. *Cognitive Psychology.* **36**(2), pp.73-137.

Hines, D. 1975. Immediate and delayed recognition of sequentially presented random shapes. *Journal of Experimental Psychology: Human Learning and Memory.* **1**(5), pp.634-639.

Hurlstone, M. J., Hitch, G. J., & Baddeley, A. D. (2014). Memory for serial order across domains: An overview of the literature and directions for future research. Psychological bulletin, 140(2), 339–373. https://doi.org/10.1037/a0034221

Jolicœur, P., & Dell'Acqua, R. (1998). The demonstration of short-term consolidation. Cognitive Psychology, 36(2), 138-202. doi: 10.1006/cogp.1998.0684

Jolicœur, P., & Dell'Acqua, R. (1999). Attentional and structural constraints on visual encoding. Psychological research, 62(2), 154-164. doi: 10.1007/s004260050048

Jones, D. et al. 1992. Privileged Access by Irrelevant Speech to Short-term Memory: The Role of Changing State. *The Quarterly Journal of Experimental Psychology Section A.* **44**(4), pp.645-669.

Jones, T. and Oberauer, K. 2013. Serial-position effects for items and relations in short-term memory. *Memory.* **21**(3), pp.347-65.

Kahana, M.J. 1996. Associative Retrieval Processes in Free Recall. *Memory & cognition.* **24**(1), pp.103-109.

Kane, M. J.; Hambrick, D. Z.; Tuholski, S. W.; Wilhelm, O.; Payne, T. W.; Engle, R. W. (2004). "The generality of working-memory capacity: A latent-variable approach to verbal and visuo-spatial memory span and reasoning". Journal of Experimental Psychology: General. 133 (2): 189–217.

Keppel, G., & Underwood, B. J. (1962). Proactive inhibition in short-term retention of single items. Journal of Verbal Learning & Verbal Behavior, 1(3), 153–161. https://doi.org/10.1016/S0022-5371(62)80023-1

Kim, J., & Yassa, M. A. (2013). Assessing recollection and familiarity of similar lures in a behavioral pattern separation task. Hippocampus, 23(4), 287-294. doi: 10.1002/hipo.22087

Knöchel, C., Oertel-Knöchel, V., Bittner, R., Stäblein, M., Heselhaus, V., Prvulovic, D., ... & Linden, D. E. (2015). Consolidation time affects performance and neural activity during visual working memory. Psychiatry Research: Neuroimaging, 231(1), 33-41. doi: 10.1016/j.pscychresns.2014.10.025

Kool, W., Conway, A. R. A., & Turk-Browne, N. B. (2014). Sequential dynamics in visual short-term memory. Attention, Perception, & Psychophysics, 76, 1885–1901

Lashley, K.S. 1951. The problem of serial order in behavior.

Lewandowsky, S., Brown, G. D., Wright, T., & Nimmo, L. M. (2006). Timeless memory: Evidence against temporal distinctiveness models of short-term memory for serial order. Journal of Memory and Language, 54(1), 20-38. doi: 10.1016/j.jml.2005.08.004

Lewandowsky, S., Ecker, U. K., Farrell, S., & Brown, G. D. (2012). Models of cognition and constraints from neuroscience: A case study involving consolidation. Australian Journal of Psychology, 64(1), 37-45. doi: 10.1111/j.1742-9536.2011.00042.x

Lewandowsky, S., Geiger, S. M., Morrell, D. B., & Oberauer, K. (2010). Turning simple span into complex span: Time for decay or interference from distractors?. Journal of Experimental Psychology: Learning, Memory, and Cognition, 36(4), 958-978. doi: 10.1037/a0019764

Lewandowsky, S., & Oberauer, K. (2009). No evidence for temporal decay in working memory. Journal of Experimental Psychology: Learning, Memory, and Cognition, 35(6), 1545-1551. doi: 10.1037/a0017010

Lewandowsky, S., & Oberauer, K. (2015). Rehearsal in serial recall: An unworkable solution to the nonexistent problem of decay. Psychological review, 122(4), 674-699. doi: 10.1037/a0039684

Lewandowsky, S., Oberauer, K., & Brown, G. D. (2009). No temporal decay in verbal short-term memory. Trends in Cognitive Sciences, 13(3), 120-126. doi: 10.1016/j.tics.2008.12.003

Lewandowsky, S. and Murdock Jr, B.B. 1989. Memory for serial order. *Psychological Review.* **96**(1), pp.25-57.

Lewandowsky, S., Nimmo, L., & Brown, G. (2008). When temporal isolation benefits memory for serial order. Journal of Memory and Language, 58(2), 415–428. https://doi.org/10.1016/j.jml.2006.11.003

Loess, H., & Harris, R. (1968). Short-term memory for individual verbal items as a function of method of recall. Journal of Experimental Psychology, 78(1), 64–69. https://doi.org/10.1037/h0026166

Luria, R., Sessa, P., Gotler, A., Jolicœur, P., & Dell'Acqua, R. (2010). Visual short-term memory capacity for simple and complex objects. Journal of cognitive neuroscience, 22(3), 496-512. doi: 10.1162/jocn.2009.21214

Makovski, T., & Jiang, Y. V. (2008). Proactive interference from items previously stored in visual working memory. Memory & Cognition, 36(1), 43-52. doi:10.3758/MC.36.1.43

Mammarella, N., Russo, R., & Avons, S. (2002). Spacing effects in cued-memory tasks for unfamiliar faces and nonwords. Memory & Cognition, 30(8), 1238–1251. https://doi.org/10.3758/BF03213406

Mathy, F., Chekaf, M., & Cowan, N. (2018). Simple and Complex Working Memory Tasks Allow Similar Benefits of Information Compression. Journal of Cognition, 1(1), 31.Mercer, T. 2014. The loss of short-term visual representations over time: decay or temporal distinctiveness? *Journal of experimental psychology. Human perception and performance.* **40**(6), pp.2281-2288.

McGaugh, J. L. (2000). Memory--a century of consolidation. Science, 287(5451), 248-251. doi: 10.1126/science.287.5451.248

McKeown, D., & Mercer, T. (2012). Short-term forgetting without interference. Journal of Experimental Psychology: Learning, Memory, And Cognition, 38, 1057-1068.

McKeown, D., Holt, J., Delvenne, J. F., Smith, A., & Griffiths, B. (2014). Active versus passive maintenance of visual nonverbal memory. Psychonomic Bulletin & Review, 21(4), 1-7. doi: 10.3758/s13423-013-0574-1

Melton, A.W. (1963). Implications of short-term memory for a general theory of memory. Journal of Verbal Learning and Verbal Behavior, 2(1), 1-21, https://doi.org/10.1016/S0022-5371(63)80063-8.

Mercer, T., & McKeown, D. (2014). Decay uncovered in nonverbal short-term memory. Psychonomic bulletin & review, 21(1), 128-135.

Mercer, T. (2014). The loss of short-term visual representations over time: Decay or temporal distinctiveness? Journal of Experimental Psychology: Human Perception and Performance, 40(6), 2281-2288. doi: 10.1037/a0038141

Morin, C., Brown, G. D. A., & Lewandowsky, S. (2010). Temporal isolation effects in recognition and serial recall. Memory & Cognition, 38, 849–859. doi:10.3758/MC.38.7.849

Morra, S. 2015. How do subvocal rehearsal and general attentional resources contribute to verbal short-term memory span? *Frontiers in psychology*. **6**, p145.

Murdock Jr, B.B. 1962. The serial position effect of free recall. *Journal of experimental psychology*. **64**(5), p482.

Nairne, J.S. 1990. A feature model of immediate memory. *Memory & Cognition*. **18**(3), pp.251-269.

Neath, I., & Brown, G. (2012). Arguments against memory trace decay: A SIMPLE account of Baddeley and Scott. Frontiers In Psychology, 3. Farrell, S. 2012. Temporal clustering and sequencing in short-term memory and episodic memory. Psychological Review. 119(2), pp.223-271.Morin, C. et al. 2010. Temporal isolation effects in recognition and serial recall. Memory & Cognition. 38(7), pp.849-859.

Neath, I. and Crowder, R.G. 1990. Schedules of presentation and temporal distinctiveness in human memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. **16**(2), pp.316-327.

Neath, I. and Crowder, R.G. 1996. Distinctiveness and Very Short-term Serial Position Effects. *Memory*. **4**(3), pp.225-242.

Nieuwenstein, M. R., & Wyble, B. (2014). Beyond decay: Limitations in visual short-term memory as a result of competition for resources. Journal of Experimental Psychology: Human Perception and Performance, 40(1), 381–400. https://doi.org/10.1037/a0034373

Nimmo, L.M. and Lewandowsky, S. 2006. Distinctiveness revisited: Unpredictable temporal isolation does not benefit short-term serial recall of heard or seen events. *Memory & Cognition.* **34**(6), pp.1368-1375.

Norman, D. A., & Waugh, N. C. (1968). Stimulus and response interference in recognition-memory experiments. Journal of Experimental Psychology, 78(4, Pt.1), 551–559. https://doi.org/10.1037/h0026637

Oberauer, K., Farrell, S., Jarrold, C., Pasiecznik, K., & Greaves, M. (2012). Interference between maintenance and processing in working memory: The effect of item–distractor similarity in complex span. Journal of Experimental Psychology: Learning, Memory, and Cognition, 38(3), 665-685. doi: 10.1037/a0026337

Oberauer, K., & Kliegl, R. (2006). A formal model of capacity limits in working memory. Journal of Memory and Language, 55(4), 601-626. doi: 10.1016/j.jml.2006.08.009

Oberauer, K., & Lewandowsky, S. (2008). Forgetting in immediate serial recall: Decay, temporal distinctiveness, or interference?. Psychological review, 115(3), 544-576. doi: 10.1037/0033-295X.115.3.544

Oberauer, K., & Lin, H. Y. (2017). An interference model of visual working memory. Psychological Review, 124(1), 21-59. doi: 10.1037/rev0000044

Oberauer, K., Awh, E., & Sutterer, D. W. (2017). The role of long-term memory in a test of visual working memory: Proactive facilitation but no proactive interference. Journal of Experimental Psychology: Learning, Memory, and Cognition, 43(1), 1-22. doi:10.1037/xlm0000302

Page, M. and Norris, D. 1998. The primacy model: a new model of immediate serial recall. *Psychological review.* **105**(4), p761.

Peteranderl, S., & Oberauer, K. (2018). Serial recall of colors: Two models of memory for serial order applied to continuous visual stimuli. Memory & cognition, 46(1), 1–16. https://doi.org/10.3758/s13421-017-0741-0

Peterson, L., & Peterson, M. J. (1959). Short-term retention of individual verbal items. Journal of Experimental Psychology, 58, 193–198. doi:10.1037/h0049234

Parmentier, F. B. R., King, S., & Dennis, I. (2006). Local temporal distinctiveness does not benefit auditory verbal and spatial serial recall. Psychonomic Bulletin & Review, 13, 458–465. doi:10.3758/BF03193870

Quinlan, J. A., Neath, I., & Surprenant, A. M. (2015). Positional uncertainty in the Brown-Peterson paradigm. Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale, 69(1), 64–71. https://doi.org/10.1037/cep0000038

Raaijmakers, J.G. and Shiffrin, R.M. 1981. Search of associative memory. *Psychological Review.* **88**(2), pp.93-134.

Raye, C. L., Johnson, M. K., Mitchell, K. J., Greene, E. J., & Johnson, M. R. (2007). Refreshing: a minimal executive function. Cortex; a journal devoted to the study of the nervous system and behavior, 43(1), 135–145. https://doi.org/10.1016/s0010-9452(08)70451-9.

Richardson, J.T.E. and Baddeley, A.D. 1975. The effect of articulatory suppression in free recall. *Journal of Verbal Learning and Verbal Behavior.* **14**(6), pp.623-629.

Ricker, T. J. (2015). The role of short-term consolidation in memory persistence. AIMS Neuroscience, 2 (4), 259-279. doi: 10.3934/Neuroscience.2015.4.259

Ricker, T. J., & Cowan, N. (2010). Loss of visual working memory within seconds: The combined use of refreshable and non-refreshable features. Journal of experimental psychology. Learning, memory, and cognition, 36(6), 1355-1368. doi: 10.1037/a0020356

Ricker, T. J., & Cowan, N. (2014). Differences between presentation methods in working memory procedures: A matter of working memory consolidation. Journal of Experimental Psychology: Learning, Memory, and Cognition, 40(2), 417-428. doi: 10.1037/a0034301

Ricker, T. J., Cowan, N., & Morey, C. C. (2010). Visual working memory is disrupted by covert verbal retrieval. Psychonomic Bulletin & Review, 17(4), 516-521. doi: 10.3758/PBR.17.4.516

Ricker, T. J., Spiegel, L. R., & Cowan, N. (2014). Time-based loss in visual short-term memory is from trace decay, not temporal distinctiveness. Journal of Experimental Psychology: Learning, Memory, and Cognition, 40(6), 1510-1523. doi: 10.1037/xlm000001

Ricker, T. J., Vergauwe, E., Hinrichs, G. A., Blume, C. L., & Cowan, N. (2015). No recovery of memory when cognitive load is decreased. Journal of experimental psychology. Learning, memory, and cognition, 41(3), 872–880. https://doi.org/10.1037/xlm0000084

Ricker, T.J., Vergauwe, E., & Cowan, N. (2016). Decay theory of immediate memory: From Brown (1958) to today (2014). Quarterly Journal of Experimental Psychology, 69, 1969-1995. doi: 10.1080/17470218.2014.914546

Romani, C. et al. 2005. Length, lexicality, and articulatory suppression in immediate recall: Evidence against the articulatory loop. *Journal of Memory and Language.* **52**(3), pp.398-415.

Ronnberg, J. (1980). Predictability as a task demand in single trial free recall. Scandinavian Journal of Psychology, 21,83–95.

Ronnberg, J. (1981). Predictability and recall strategy for nominal serial position curves. Scandinavian Journal of Psychology, 22, 189–195.

Schendel, Z.A. and Palmer, C. 2007. Suppression effects on musical and verbal memory. *Memory & Cognition.* **35**(4), pp.640-650.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002) E-Prime User's Guide. Pittsburgh: Psychology Software Tools Inc. Retrieved from http://www.pstnet.com/eprime.cfm

Sikström, S. (2006). The Isolation, Primacy, and Recency Effects Predicted by an Adaptive LTD/LTP Threshold in Postsynaptic Cells. Cognitive Science, 30(2), 243–275. https://doi.org/10.1207/s15516709cog0000_55

Shipstead, Z., & Engle, R. W. (2013). Interference within the focus of attention: Working memory tasks reflect more than temporary maintenance. Journal of Experimental Psychology: Learning, Memory, and Cognition, 39(1), 277-289. doi: 10.1037/a0028467

Smith, A.V., McKeown, J.D. and Bunce, D. Time manages interference in visual short-term memory. Memory, 25 (8). pp. 1117-1128. ISSN 0965-8211

Smyth, M.M. and Scholey, K.A. 1996. The Relationship between Articulation Time and Memory Performance in Verbal and Visuospatial Tasks. *British Journal of Psychology.* **87**(2), pp.179-191.

Souza, A. S., & Oberauer, K. (2014). Time-based forgetting in visual working memory reflects temporal distinctiveness, not decay. Psychonomic Bulletin & Review, 22(1), 156-162. doi: 10.3758/s13423-014-0652-z

Souza, A.S. and Oberauer, K. 2015. Time-based forgetting in visual working memory reflects temporal distinctiveness, not decay. *Psychon Bull Rev.* **22**(1), pp.156-62.

Sperling, G. (1960). The information available in brief visual presentations. Psychological Monographs: General and Applied, 74(11), 1–29. https://doi.org/10.1037/h0093759

Stevanovski, B., & Jolicœur, P. (2007). Visual short-term memory: Central capacity limitations in short-term consolidation. Visual Cognition, 15(5), 532-563. doi: 10.1080/13506280600871917

Stevanovski, B., & Jolicœur, P. (2011). Consolidation of multifeature items in visual working memory: Central capacity requirements for visual consolidation. Attention, Perception, & Psychophysics, 73(4), 1108-1119. doi: 10.3758/s13414-011-0099-5.

Trapp, S., Mueller, K., Lepsien, J., Krämer, B., & Gruber, O. (2014). Different neural capacity limitations for articulatory and non-articulatory maintenance of verbal information. Experimental brain research, 232(2), 619–628. https://doi.org/10.1007/s00221-013-3770-3

Tulving, E. and Pearlstone, Z. 1966. Availability versus accessibility of information in memory for words. *Journal of Verbal Learning and Verbal Behavior.* **5**(4), pp.381-391.

Tulving, E. (2002). Episodic memory: from mind to brain. Annual review of psychology, 53(1), 1-25. doi: 10.1146/annurev.psych.53.100901.135114

Tulving, E., & Markowitsch, H. J. (1998). Episodic and declarative memory: role of the hippocampus. Hippocampus, 8(3), 198-204. doi: 10.1002/(SICI)1098-1063(1998)8:3<198::AID-HIPO2>3.0.CO;2-G

Unsworth, N., Heitz, R. P., & Parks, N. A. (2008). The importance of temporal distinctiveness for forgetting over the short term. Psychological Science, 19(11), 1078-1081. doi: 10.1111/j.1467-9280.2008.02203.x

Vaughan, L., & Hartman, M. (2009). Aging and visual short-term memory: Effects of object type and information load. Aging, Neuropsychology, and Cognition, 17(1), 35-54. doi: 10.1080/13825580903009063

Vergauwe, E., Dewaele, N., Langerock, N., & Barrouillet, P. (2012). Evidence for a central pool of general resources in working memory. Journal of Cognitive Psychology, 24(3), 359-366. doi: 10.1080/20445911.2011.640625

Vergauwe, E., Hartstra, E., Barrouillet, P., & Brass, M. (2015). Domain-general involvement of the posterior frontolateral cortex in time-based resource-sharing in working memory: An fMRI study. NeuroItem, 115, 104-116. doi: 10.1016/j.neuroitem.2015.04.059

Underwood, B. (1957). Interference and forgetting. Psychological Review, 64, 49-60.

Vergauwe, E., Barrouillet, P., & Camos, V. (2010). Do mental processes share a domain-general resource?. Psychological Science, 21, 384–390.

Ward, G. et al. 2007. Serial position curves in short-term memory: Functional equivalence across modalities. *Memory.* **13**(3-4), pp.308-317.

Waugh, N. C., & Norman, D. A. (1965). Primary memory. Psychological review, 72(2), 89. doi: 10.1037/h0021797

Welte, J.W. and Laughery, K.R. 1971. Short-term memory: The effects of inter-item time distribution and recall procedure. *Canadian Journal of Psychology/Revue canadienne de psychologie.* **25**(6), p436.

Wingfield A, Byrnes DL. Decay of information in short-term memory. Science. 1972;176(4035):690-692. doi:10.1126/science.176.4035.690

White, A. L., & Gresch, D. (2016). Restoring visual memory: The benefit of temporal isolation. Journal of Vision, 16(12), 345. https://doi.org/10.1167/16.12.345

Winzenz, D. and Bower, G.H. 1970. Subject-imposed coding and memory for digit series. *Journal of Experimental Psychology.* **83**(1, Pt.1), pp.52-56.

Wixted, J. T. (2004). The psychology and neuroscience of forgetting. Annual Review of Psychology, 55, 235-269. doi: 10.1146/annurev.psych.55.090902.141555

Zhang, W., & Luck, S. J. (2008). Discrete fixed-resolution representations in visual working memory. Nature, 453(7192), 233-235. doi: 10.1038/nature06860

Zhang, W., & Luck, S. J. (2009). Sudden death and gradual decay in visual working memory. Psychological Science, 20(4), 423-428. doi: 10.1111/j.1467-9280.2009.02322.x

Chapter 10 - Appendices

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Increasing ISI Free Recall	30.5667	30	6.09513	1.11281
	Decreasing ISI Free Recall	32.5667	30	7.61434	1.39018
Pair 2	Increasing ISI Free Recall	30.5667	30	6.09513	1.11281
	Fixed Irregular ISI Free Recall	37.0667	30	7.34816	1.34158
Pair 3	Increasing ISI Free Recall	30.5667	30	6.09513	1.11281
	Increasing ISI Serial Recall	28.8667	30	5.22417	.95380
Pair 4	Increasing ISI Free Recall	30.5667	30	6.09513	1.11281
	Decreasing ISI Serial Recall	26.2000	30	6.16665	1.12587
Pair 5	Increasing ISI Free Recall	30.5667	30	6.09513	1.11281
	Fixed Irregular ISI Serial Recall	30.5667	30	7.33289	1.33880
Pair 6	Decreasing ISI Free Recall	32.5667	30	7.61434	1.39018
	Fixed Irregular ISI Free Recall	37.0667	30	7.34816	1.34158
Pair 7	Decreasing ISI Free Recall	32.5667	30	7.61434	1.39018
	Increasing ISI Serial Recall	28.8667	30	5.22417	.95380
Pair 8	Decreasing ISI Free Recall	32.5667	30	7.61434	1.39018
	Decreasing ISI Serial Recall	26.2000	30	6.16665	1.12587
Pair 9	Decreasing ISI Free Recall	32.5667	30	7.61434	1.39018
	Fixed Irregular ISI Serial Recall	30.5667	30	7.33289	1.33880
Pair 10	Fixed Irregular ISI Free Recall	37.0667	30	7.34816	1.34158
	Increasing ISI Serial Recall	28.8667	30	5.22417	.95380
Pair 11	Fixed Irregular ISI Free Recall	37.0667	30	7.34816	1.34158
	Decreasing ISI Serial Recall	26.2000	30	6.16665	1.12587
Pair 12	Fixed Irregular ISI Free Recall	37.0667	30	7.34816	1.34158
	Fixed Irregular ISI Serial Recall	30.5667	30	7.33289	1.33880
Pair 13	Increasing ISI Serial Recall	28.8667	30	5.22417	.95380
	Decreasing ISI Serial Recall	26.2000	30	6.16665	1.12587
Pair 14	Increasing ISI Serial Recall	28.8667	30	5.22417	.95380
	Fixed Irregular ISI Serial Recall	30.5667	30	7.33289	1.33880
Pair 15	Decreasing ISI Serial Recall	26.2000	30	6.16665	1.12587
	Fixed Irregular ISI Serial Recall	30.5667	30	7.33289	1.33880

Table 1 Descriptive statistics for Paired samples t test to compare recall between the different item lag conditions (Decreasing, Increasing and Fixed Irregular ISI) and the different recall conditions (free and serial recall) – Experiment 1

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Increasing ISI Free Recall - Decreasing ISI Free Recall	-2.00000	5.23911	.95653	-3.95632	-.04368	-2.091	29	.045
Pair 2	Increasing ISI Free Recall - Fixed Irregular ISI Free Recall	-6.50000	5.61863	1.02582	-8.59803	-4.40197	-6.336	29	.000
Pair 3	Increasing ISI Free Recall - Increasing ISI Serial Recall	1.70000	4.41900	.80680	.04992	3.35008	2.107	29	.044
Pair 4	Increasing ISI Free Recall - Decreasing ISI Serial Recall	4.36667	4.64226	.84756	2.63322	6.10011	5.152	29	.000
Pair 5	Increasing ISI Free Recall - Fixed Irregular ISI Serial Recall	.00000	5.28498	.96490	-1.97344	1.97344	.000	29	1.000
Pair 6	Decreasing ISI Free Recall - Fixed Irregular ISI Free Recall	-4.50000	6.05578	1.10563	-6.76126	-2.23874	-4.070	29	.000
Pair 7	Decreasing ISI Free Recall - Increasing ISI Serial Recall	3.70000	4.79331	.87514	1.91015	5.48985	4.228	29	.000
Pair 8	Decreasing ISI Free Recall - Decreasing ISI Serial Recall	6.36667	4.88123	.89119	4.54398	8.18935	7.144	29	.000
Pair 9	Decreasing ISI Free Recall - Fixed Irregular ISI Serial Recall	2.00000	2.93610	.53606	.90364	3.09636	3.731	29	.001
Pair 10	Fixed Irregular ISI Free Recall - Increasing ISI Serial Recall	8.20000	5.39092	.98424	6.18700	10.21300	8.331	29	.000
Pair 11	Fixed Irregular ISI Free Recall - Decreasing ISI Serial Recall	10.86667	5.55060	1.01340	8.79404	12.93930	10.723	29	.000
Pair 12	Fixed Irregular ISI Free Recall - Fixed Irregular ISI Serial Recall	6.50000	4.77602	.87198	4.71661	8.28339	7.454	29	.000
Pair 13	Increasing ISI Serial Recall - Decreasing ISI Serial Recall	2.66667	4.11334	.75099	1.13072	4.20261	3.551	29	.001
Pair 14	Increasing ISI Serial Recall - Fixed Irregular ISI Serial Recall	-1.70000	4.33232	.79097	-3.31771	-.08229	-2.149	29	.040
Pair 15	Decreasing ISI Serial Recall - Fixed Irregular ISI Serial Recall	-4.36667	4.01277	.73263	-5.86506	-2.86827	-5.960	29	.000

Table 2 Paired samples t test to compare recall between the different item lag conditions (Decreasing, Increasing and Fixed Irregular ISI) and the different recall conditions (free and serial recall) – Experiment 1

Paired Samples Statistics					
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Increasing ISI Trial (without distractor - Rehearsal Group)	29.2667	15	6.68117	1.72507
	Decreasing ISI Trial (without distractor - Rehearsal Group)	29.4667	15	6.11633	1.57923
Pair 2	Increasing ISI Trial (without distractor - Rehearsal Group)	29.2667	15	6.68117	1.72507
	Equal ISI Trial (without distractor - Rehearsal Group)	27.8000	15	7.38918	1.90788
Pair 3	Decreasing ISI Trial (without distractor - Rehearsal Group)	29.4667	15	6.11633	1.57923
	Equal ISI Trial (without distractor - Rehearsal Group)	27.8000	15	7.38918	1.90788
Pair 4	Increasing ISI Trial (without distractor - Rehearsal Group)	29.2667	15	6.68117	1.72507
	Increasing ISI Trial (controlled for Articulatory Rehearsal)	18.0667	15	5.31126	1.37136
Pair 5	Decreasing ISI Trial (without distractor - Rehearsal Group)	29.4667	15	6.11633	1.57923
	Decreasing ISI Trial (controlled for Articulatory Rehearsal)	19.1333	15	5.71797	1.47637
Pair 6	Equal ISI Trial (without distractor - Rehearsal Group)	27.8000	15	7.38918	1.90788
	Equal ISI Trial (controlled for Articulatory Rehearsal)	20.1333	15	7.66128	1.97813
Pair 7	Increasing ISI Trial (controlled for Articulatory Rehearsal)	18.0667	15	5.31126	1.37136
	Decreasing ISI Trial (controlled for Articulatory Rehearsal)	19.1333	15	5.71797	1.47637
Pair 8	Increasing ISI Trial (controlled for Articulatory Rehearsal)	18.0667	15	5.31126	1.37136
	Equal ISI Trial (controlled for Articulatory Rehearsal)	20.1333	15	7.66128	1.97813
Pair 9	Decreasing ISI Trial (controlled for Articulatory Rehearsal)	19.1333	15	5.71797	1.47637
	Equal ISI Trial (controlled for Articulatory Rehearsal)	20.1333	15	7.66128	1.97813

Table 3 Descriptive statistics for Paired samples t test to compare recall between the different item lag conditions (Decreasing, Increasing and Equal ISI) in the Rehearsal group – Experiment 2

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper			
Pair 1	Increasing ISI Trial (without distractor - Rehearsal Group) - Decreasing ISI Trial (without distractor - Rehearsal Group)	-.20000	4.66292	1.20396	-2.78224	2.38224	-.166	14	.870
Pair 2	Increasing ISI Trial (without distractor - Rehearsal Group) - Equal ISI Trial (without distractor - Rehearsal Group)	1.46667	3.29213	.85002	-.35645	3.28979	1.725	14	.106
Pair 3	Decreasing ISI Trial (without distractor - Rehearsal Group) - Equal ISI Trial (without distractor - Rehearsal Group)	1.66667	4.41858	1.14087	-.78026	4.11359	1.461	14	.166
Pair 4	Increasing ISI Trial (without distractor - Rehearsal Group) - Increasing ISI Trial (controlled for Articulatory Rehearsal)	11.20000	5.33452	1.37737	8.24584	14.15416	8.131	14	.000
Pair 5	Decreasing ISI Trial (without distractor - Rehearsal Group) - Decreasing ISI Trial (controlled for Articulatory Rehearsal)	10.33333	5.10835	1.31897	7.50442	13.16224	7.834	14	.000
Pair 6	Equal ISI Trial (without distractor - Rehearsal Group) - Equal ISI Trial (controlled for Articulatory Rehearsal)	7.66667	4.08248	1.05409	5.40586	9.92747	7.273	14	.000
Pair 7	Increasing ISI Trial (controlled for Articulatory Rehearsal) - Decreasing ISI Trial (controlled for Articulatory Rehearsal)	-1.06667	4.26726	1.10180	-3.42980	1.29646	-.968	14	.349
Pair 8	Increasing ISI Trial (controlled for Articulatory Rehearsal) - Equal ISI Trial (controlled for Articulatory Rehearsal)	-2.06667	6.57340	1.69724	-5.70689	1.57356	-1.22	14	.243
Pair 9	Decreasing ISI Trial (controlled for Articulatory Rehearsal) - Equal ISI Trial (controlled for Articulatory Rehearsal)	-1.00000	4.85504	1.25357	-3.68863	1.68863	-.798	14	.438

Table 4 Paired samples t test to compare recall between the different item lag conditions (Decreasing, Increasing and Equal ISI) in the Rehearsal group – Experiment 2

Paired Samples Statistics					
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Increasing ISI Trial (without distractor - Refreshing Group)	28.6000	15	4.65679	1.20238
	Decreasing ISI Trial(without distractor - Refreshing Group)	25.5333	15	5.15290	1.33047
Pair 2	Increasing ISI Trial (without distractor - Refreshing Group)	28.6000	15	4.65679	1.20238
	Equal ISI Trial(without distractor - Refreshing Group)	29.0000	15	4.84031	1.24976
Pair 3	Decreasing ISI Trial(without distractor - Refreshing Group)	25.5333	15	5.15290	1.33047
	Equal ISI Trial(without distractor - Refreshing Group)	29.0000	15	4.84031	1.24976
Pair 4	Increasing ISI Trial (without distractor - Refreshing Group)	28.6000	15	4.65679	1.20238
	Increasing ISI Trial (controlled for Attentional Refreshing)	19.9333	15	5.43095	1.40227
Pair 5	Decreasing ISI Trial(without distractor - Refreshing Group)	25.5333	15	5.15290	1.33047
	Decreasing ISI Trial (controlled for Attentional Refreshing)	20.3333	15	5.16398	1.33333
Pair 6	Equal ISI Trial(without distractor - Refreshing Group)	29.0000	15	4.84031	1.24976
	Equal ISI Trial (controlled for Attentional Refreshing)	22.5333	15	5.27618	1.36230
Pair 7	Increasing ISI Trial (controlled for Attentional Refreshing)	19.9333	15	5.43095	1.40227
	Decreasing ISI Trial (controlled for Attentional Refreshing)	20.3333	15	5.16398	1.33333
Pair 8	Increasing ISI Trial (controlled for Attentional Refreshing)	19.9333	15	5.43095	1.40227
	Equal ISI Trial (controlled for Attentional Refreshing)	22.5333	15	5.27618	1.36230
Pair 9	Decreasing ISI Trial (controlled for Attentional Refreshing)	20.3333	15	5.16398	1.33333
	Equal ISI Trial (controlled for Attentional Refreshing)	22.5333	15	5.27618	1.36230

Table 5 Descriptive statistics for Paired samples t test to compare recall between the different item lag conditions (Decreasing, Increasing and Equal ISI) in the Refreshing Group – Experiment 2

Paired Samples Test										
		Paired Differences						t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference					
					Lower	Upper				
Pair 1	Increasing ISI Trial (without distractor - Refreshing Group) - Decreasing ISI Trial(without distractor - Refreshing Group)	3.06667	4.78788	1.23623	.41523	5.71811		2.481	14	.026
Pair 2	Increasing ISI Trial (without distractor - Refreshing Group) - Equal ISI Trial(without distractor - Refreshing Group)	-.40000	4.68737	1.21027	-2.99578	2.19578		-.331	14	.746
Pair 3	Decreasing ISI Trial(without distractor - Refreshing Group) - Equal ISI Trial(without distractor - Refreshing Group)	-3.4667	4.30725	1.11213	-5.85194	-1.08139		-3.12	14	.008
Pair 4	Increasing ISI Trial (without distractor - Refreshing Group) - Increasing ISI Trial (controlled for Attentional Refreshing)	8.66667	6.14894	1.58765	5.26149	12.07184		5.459	14	.000
Pair 5	Decreasing ISI Trial(without distractor - Refreshing Group) - Decreasing ISI Trial (controlled for Attentional Refreshing)	5.20000	5.64674	1.45798	2.07294	8.32706		3.567	14	.003
Pair 6	Equal ISI Trial(without distractor - Refreshing Group) - Equal ISI Trial (controlled for Attentional Refreshing)	6.46667	5.76773	1.48922	3.27261	9.66073		4.342	14	.001
Pair 7	Increasing ISI Trial (controlled for Attentional Refreshing) - Decreasing ISI Trial (controlled for Attentional Refreshing)	-.40000	4.38830	1.13305	-2.83016	2.03016		-.353	14	.729
Pair 8	Increasing ISI Trial (controlled for Attentional Refreshing) - Equal ISI Trial (controlled for Attentional Refreshing)	-2.600	4.71775	1.21812	-5.21260	.01260		-2.13	14	.051
Pair 9	Decreasing ISI Trial (controlled for Attentional Refreshing) - Equal ISI Trial (controlled for Attentional Refreshing)	-2.200	3.91335	1.01042	-4.36714	-.03286		-2.18	14	.047

Table 6 Paired samples t test to compare recall between the different item lag conditions (Decreasing, Increasing and Equal ISI) in the Refreshing group – Experiment 2

Group Statistics – Rehearsal and Refreshing Groups					
	Groups	N	Mean	Std. Deviation	Std. Error Mean
Increasing ISI Trial (without distractor)	Rehearsal Group	15	29.2667	6.68117	1.72507
	Refreshing Group	15	28.6000	4.65679	1.20238
Decreasing ISI Trial (without distractor)	Rehearsal Group	15	29.4667	6.11633	1.57923
	Refreshing Group	15	25.5333	5.15290	1.33047
Equal ISI Trial (without distractor)	Rehearsal Group	15	27.8000	7.38918	1.90788
	Refreshing Group	15	29.0000	4.84031	1.24976
Increasing ISI Trial (with distractor)	Rehearsal Group	15	18.0667	5.31126	1.37136
	Refreshing Group	15	19.9333	5.43095	1.40227
Decreasing ISI Trial (with distractor)	Rehearsal Group	15	19.1333	5.71797	1.47637
	Refreshing Group	15	20.3333	5.16398	1.33333
Equal ISI Trial (with distractor)	Rehearsal Group	15	20.1333	7.66128	1.97813
	Refreshing Group	15	22.5333	5.27618	1.36230

Table 7 Descriptive statistics for Independent samples t test to compare recall between the different item lag conditions (Decreasing, Increasing and Equal ISI) and the different groups (Rehearsal group and Refreshing group) – Experiment 2

Independent Samples Test									
	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Increasing ISI Trial (without distractor)	1.106	.302	.317	28	.754	.66667	2.10276	-3.64064	4.97397
Decreasing ISI Trial (without distractor)	.021	.885	1.905	28	.067	3.93333	2.06498	-.29658	8.16325
Equal ISI Trial (without distractor)	2.924	.098	-.526	28	.603	-1.20000	2.28077	-5.87194	3.47194
Increasing ISI Trial (with distractor)	.316	.579	-.952	28	.349	-1.86667	1.96137	-5.88436	2.15102
Decreasing ISI Trial (with distractor)	.006	.941	-.603	28	.551	-1.20000	1.98934	-5.27497	2.87497
Equal ISI Trial (with distractor)	2.412	.132	-.999	28	.326	-2.40000	2.40185	-7.31997	2.51997

Table 8 Independent samples t test to compare recall between the different item lag conditions (Decreasing, Increasing and Equal ISI) and the different groups (Rehearsal group and Refreshing group) – Experiment 2

Paired Samples Statistics					
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Equal ISI	2.9677	124	1.17519	.10553
	Decreasing ISI	3.3468	124	1.18283	.10622

Table 9 Descriptive statistics for Paired samples t test to compare recall between the different item lag conditions (Decreasing ISI and Equal ISI) – Experiment 3

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Equal ISI - Decreasing ISI	-.37903	1.51197	.13578	-.64780	-.11027	-2.792	123	.006

Table 10 Paired samples t test to compare recall between the different item lag conditions (Decreasing ISI and Equal ISI) – Experiment 3

Group Statistics

	Procedure	N	Mean	Std. Deviation	Std. Error Mean
Accuracy - Serial Position1	Equal ISI	30	.8000	.40684	.07428
	Decreasing ISI	29	.8276	.38443	.07139
Accuracy - Serial Position2	Equal ISI	30	.6667	.47946	.08754
	Decreasing ISI	29	.9310	.25788	.04789
Accuracy - Serial Position3	Equal ISI	30	.9333	.25371	.04632
	Decreasing ISI	29	.8966	.30993	.05755
Accuracy - Serial Position4	Equal ISI	30	.6667	.47946	.08754
	Decreasing ISI	29	.5862	.50123	.09308
Accuracy - Serial Position5	Equal ISI	30	.8333	.37905	.06920
	Decreasing ISI	29	.7241	.45486	.08447
Response Time - Serial Position1	Equal ISI	30	1322.4667	476.71019	87.03497
	Decreasing ISI	29	1450.6207	532.76163	98.93135
Response Time - Serial Position2	Equal ISI	30	1502.0667	740.02870	135.11014
	Decreasing ISI	29	1451.0345	460.25160	85.46658
Response Time - Serial Position3	Equal ISI	30	1286.3667	625.92720	114.27815
	Decreasing ISI	29	1343.7241	679.31131	126.14494
Response Time - Serial Position4	Equal ISI	30	1524.2333	717.59064	131.01353
	Decreasing ISI	29	1707.8966	792.76363	147.21251
Response Time - Serial Position5	Equal ISI	30	1437.7333	791.11662	144.43747
	Decreasing ISI	29	1640.5862	827.87756	153.73300
Position Accuracy - Serial Position1	Equal ISI	30	.5333	.50742	.09264
	Decreasing ISI	29	.5517	.50612	.09398
Position Accuracy - Serial Position2	Equal ISI	30	.4000	.49827	.09097
	Decreasing ISI	29	.4828	.50855	.09443
Position Accuracy - Serial Position3	Equal ISI	30	.7000	.46609	.08510
	Decreasing ISI	29	.7241	.45486	.08447
Position Accuracy - Serial Position4	Equal ISI	30	.2667	.44978	.08212
	Decreasing ISI	29	.3103	.47082	.08743
Position Accuracy - Serial Position5	Equal ISI	30	.5000	.50855	.09285
	Decreasing ISI	29	.3448	.48373	.08983
Position Response Time - Serial Position1	Equal ISI	30	1601.1000	2539.81144	463.70401
	Decreasing ISI	29	1542.9310	799.09717	148.38862
Position Response Time - Serial Position2	Equal ISI	30	1678.3333	806.95222	147.32864
	Decreasing ISI	29	1595.4483	512.05947	95.08706
Position Response Time - Serial Position3	Equal ISI	30	1420.1000	704.85261	128.68789
	Decreasing ISI	29	1555.3793	643.94589	119.57775
Position Response Time - Serial Position4	Equal ISI	30	1504.5667	630.90945	115.18778
	Decreasing ISI	29	1380.5862	582.98294	108.25721
Position Response Time - Serial Position5	Equal ISI	30	1654.2000	1236.83479	225.81411
	Decreasing ISI	29	1346.5862	778.26958	144.52103

Table 11 Descriptive statistics for independent samples t test comparing the means of the decreasing ISI group and the equal ISI group – Experiment 4

Independent Samples Test									
	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Accuracy - Serial Position1	.288	.594	-.268	57	.790	-.02759	.10312	-.23408	.17891
Accuracy - Serial Position2	39.511	.000	-2.624	57	.011	-.26437	.10073	-.46608	-.06265
Accuracy - Serial Position3	1.012	.319	.500	57	.619	.03678	.07363	-.11065	.18422
Accuracy - Serial Position4	1.465	.231	.630	57	.531	.08046	.12768	-.17521	.33613
Accuracy - Serial Position5	4.131	.047	1.003	57	.320	.10920	.10886	-.10879	.32718
Response Time – SP1	.859	.358	-.974	57	.334	-128.15402	131.51548	-391.50922	135.20118
Response Time – SP2	2.735	.104	.317	57	.753	51.03218	161.09639	-271.55777	373.62214
Response Time – SP3	.069	.794	-.337	57	.737	-57.35747	169.97219	-397.72091	283.00597
Response Time – SP4	.604	.440	-.934	57	.354	-183.66322	196.73148	-577.61121	210.28477
Response Time – SP5	.419	.520	-.962	57	.340	-202.85287	210.77574	-624.92400	219.21826
Position Accuracy – SP1	.075	.785	-.139	57	.890	-.01839	.13197	-.28266	.24588
Position Accuracy – SP2	1.067	.306	-.631	57	.530	-.08276	.13108	-.34524	.17972
Position Accuracy – SP3	.162	.689	-.201	57	.841	-.02414	.11995	-.26433	.21606
Position Accuracy – SP4	.529	.470	-.364	57	.717	-.04368	.11985	-.28368	.19632
Position Accuracy – SP5	3.089	.084	1.200	57	.235	.15517	.12930	-.10374	.41409
Position Response Time - SP1	.544	.464	.118	57	.907	58.16897	493.79991	-930.64829	1046.98622
Position Response Time – SP2	2.969	.090	.469	57	.641	82.88506	176.64147	-270.83339	436.60351
Position Response Time – SP3	.494	.485	-.769	57	.445	-135.27931	175.94174	-487.59656	217.03794
Position Response Time – SP4	.050	.823	.783	57	.437	123.98046	158.29053	-192.99087	440.95179
Position Response Time – SP5	3.447	.069	1.139	57	.260	307.61379	270.10944	-233.27102	848.49861

Table 12 Independent samples t test comparing the means of the decreasing ISI group and the equal ISI group – Experiment 4

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Accuracy	Decreasing ISI	.7388	17	.12242	.02969
	Increasing ISI	.6453	17	.13547	.03286
Response Time	Decreasing ISI	1331.6806	17	565.13988	137.06655
	Increasing ISI	1297.1029	17	488.77862	118.54623

Table 13 Paired samples t test comparing the means between decreasing ISI and increasing ISI condition – Experiment 5

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper			
Accuracy	Decreasing ISI – Increasing ISI	.09353	.11146	.02703	.03622	.15084	3.460	16	.003
Response Time	Decreasing ISI – Increasing ISI	34.57765	247.79124	60.09820	-92.82485	161.98015	.575	16	.573

Table 14 Paired samples t test comparing the means between decreasing ISI and increasing ISI condition – Experiment 5

Paired Samples Statistics					
		Mean	N	Std. Deviation	Std. Error Mean
Accuracy	Decreasing ISI with 1 s RI	.8259	17	.08952	.02171
	Decreasing ISI with 7.5 s RI	.5553	17	.16905	.04100
Response Time	Decreasing ISI with 1 s RI	1284.4641	17	360.52673	87.44057
	Decreasing ISI with 7.5 s RI	1286.9306	17	396.45338	96.15407

Table 15 Descriptive statistics for paired samples t test comparing the means between decreasing ISI with alternating retention intervals – Experiment 5

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Accuracy	Decreasing ISI with 1 s RI - Decreasing ISI with 7.5 s RI	.27059	.13479	.03269	.20129	.33989	8.277	16	.000
Response Time	Decreasing ISI with 1 s RI - Decreasing ISI with 7.5 s RI	-2.46647	205.48894	49.83839	-108.11913	103.18619	-.049	16	.961

Table 16 Paired samples t test comparing the means between decreasing ISI with alternating retention intervals – Experiment 5

Group Statistics					
	Group	N	Mean	Std. Deviation	Std. Error Mean
Accuracy SP1	No RI Group	17	.6629	.15202	.03687
	1 sec RI Group	17	.6935	.12649	.03068
Accuracy SP2	No RI Group	17	.5871	.22421	.05438
	1 sec RI Group	17	.7812	.16722	.04056
Accuracy SP3	No RI Group	17	.6406	.14716	.03569
	1 sec RI Group	17	.8841	.14803	.03590
Accuracy SP4	No RI Group	17	.5676	.20813	.05048
	1 sec RI Group	17	.8553	.12605	.03057
Accuracy SP5	No RI Group	17	.8459	.11097	.02691
	1 sec RI Group	17	.9418	.08819	.02139
Accuracy SP1	No RI Group	17	.6629	.15202	.03687
	7.5 sec RI Group	17	.6047	.17230	.04179
Accuracy SP2	No RI Group	17	.5871	.22421	.05438
	7.5 sec RI Group	17	.4947	.30340	.07359
Accuracy SP3	No RI Group	17	.6406	.14716	.03569
	7.5 sec RI Group	17	.5688	.21601	.05239
Accuracy SP4	No RI Group	17	.5676	.20813	.05048
	7.5 sec RI Group	17	.4288	.15941	.03866
Accuracy SP5	No RI Group	17	.8459	.11097	.02691
	7.5 sec RI Group	17	.6747	.21024	.05099
Response Time SP1	No RI Group	17	978.3459	293.82803	71.26376
	1 sec RI Group	17	1348.3618	719.36205	174.47093
Response Time SP2	No RI Group	17	925.6741	265.06234	64.28706
	1 sec RI Group	17	1308.0829	382.11800	92.67723
Response Time SP3	No RI Group	17	970.4176	312.15816	75.70947
	1 sec RI Group	17	1321.4729	417.00024	101.13741
Response Time SP4	No RI Group	17	901.9024	295.63684	71.70247
	1 sec RI Group	17	1335.2447	386.40063	93.71592
Response Time SP5	No RI Group	17	731.8665	187.42793	45.45795
	1 sec RI Group	17	1084.1165	325.90123	79.04266
Response Time SP1	No RI Group	17	978.3459	293.82803	71.26376
	7.5 sec RI Group	17	1255.6941	390.95426	94.82034
Response Time SP2	No RI Group	17	925.6741	265.06234	64.28706
	7.5 sec RI Group	17	1370.0029	554.95479	134.59631
Response Time SP3	No RI Group	17	970.4176	312.15816	75.70947
	7.5 sec RI Group	17	1266.3335	324.53259	78.71071
Response Time SP4	No RI Group	17	901.9024	295.63684	71.70247
	7.5 sec RI Group	17	1272.3188	434.16081	105.29946
Response Time SP5	No RI Group	17	731.8665	187.42793	45.45795
	7.5 sec RI Group	17	1272.1635	376.25726	91.25579

Table 17 Descriptive statistics for Independent samples t test comparing the means between decreasing ISI with no RI and decreasing ISI with 1 sec RI or 7.5 sec RI – Experiment 5

Groups	Independent Samples Test									
				t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
No RI vs 1 sec RI	Accuracy SP1	.173	.681	-.638	32	.528	-.03059	.04796	-.12829	.06711
	Accuracy SP2	1.118	.298	-2.862	32	.007	-.19412	.06784	-.33230	-.05594
	Accuracy SP3	.131	.720	-4.810	32	.000	-.24353	.05062	-.34665	-.14041
	Accuracy SP4	3.289	.079	-4.874	32	.000	-.28765	.05902	-.40786	-.16744
	Accuracy SP5	.001	.982	-2.789	32	.009	-.09588	.03438	-.16591	-.02586
No RI vs 7.5 sec RI	Accuracy SP1	.468	.499	1.045	32	.304	.05824	.05573	-.05528	.17175
	Accuracy SP2	1.758	.194	1.009	32	.320	.09235	.09150	-.09402	.27873
	Accuracy SP3	2.580	.118	1.132	32	.266	.07176	.06339	-.05736	.20089
	Accuracy SP4	1.008	.323	2.183	32	.036	.13882	.06358	.00931	.26834
	Accuracy SP5	6.138	.019	2.969	32	.006	.17118	.05766	.05373	.28862
No RI vs 1 sec RI	Response Time SP1	3.229	.082	-1.963	32	.058	-370.01588	188.46386	-753.90421	13.87245
	Response Time SP2	4.031	.053	-3.390	32	.002	-382.40882	112.79138	-612.15734	-152.66031
	Response Time SP3	1.944	.173	-2.779	32	.009	-351.05529	126.33567	-608.39263	-93.71796
	Response Time SP4	.822	.371	-3.672	32	.001	-433.34235	117.99965	-673.69977	-192.98493
	Response Time SP5	5.066	.031	-3.863	32	.001	-352.25000	91.18205	-537.98177	-166.51823
No RI vs 7.5 sec RI	Response Time SP1	.246	.623	-2.338	32	.026	-277.34824	118.61459	-518.95824	-35.73823
	Response Time SP2	2.159	.151	-2.979	32	.005	-444.32882	149.16096	-748.15976	-140.49789
	Response Time SP3	.207	.652	-2.710	32	.011	-295.91588	109.21218	-518.37382	-73.45794
	Response Time SP4	1.182	.285	-2.908	32	.007	-370.41647	127.39396	-629.90947	-110.92347
	Response Time SP5	5.089	.031	-5.300	32	.000	-540.29706	101.95119	-747.96483	-332.62929

Table 18 Independent samples t test comparing the means between decreasing ISI with no RI and decreasing ISI with 1 sec RI or 7.5 sec RI – Experiment 5

Paired Samples Statistics					
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Accuracy for SP1 in Equal ISI	71.33	18	13.002	3.065
	Accuracy for SP1 in Decreasing ISI	77.72	18	17.201	4.054
Pair 2	Accuracy for SP2 in Equal ISI	65.39	18	17.701	4.172
	Accuracy for SP2 in Decreasing ISI	68.94	18	16.458	3.879
Pair 3	Accuracy for SP3 in Equal ISI	60.22	18	15.750	3.712
	Accuracy for SP3 in Decreasing ISI	63.78	18	13.176	3.106
Pair 4	Accuracy for SP4 in Equal ISI	58.33	18	14.504	3.419
	Accuracy for SP4 in Decreasing ISI	59.06	18	14.186	3.344
Pair 5	Accuracy for SP5 in Equal ISI	57.89	18	14.037	3.309
	Accuracy for SP5 in Decreasing ISI	57.78	18	10.201	2.404
Pair 6	Accuracy for SP6 in Equal ISI	60.44	18	10.153	2.393
	Accuracy for SP6 in Decreasing ISI	60.17	18	10.416	2.455

Table 19 Descriptive statistics for paired samples t test comparing the means for accuracy of the different serial positions between decreasing ISI and equal ISI – Experiment 6

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Accuracy for SP1 in Equal ISI - Accuracy for SP1 in Decreasing ISI	-6.389	17.385	4.098	-15.034	2.257	-1.559	17	.137
Pair 2	Accuracy for SP2 in Equal ISI - Accuracy for SP2 in Decreasing ISI	-3.556	12.249	2.887	-9.647	2.535	-1.232	17	.235
Pair 3	Accuracy for SP3 in Equal ISI - Accuracy for SP3 in Decreasing ISI	-3.556	11.552	2.723	-9.300	2.189	-1.306	17	.209
Pair 4	Accuracy for SP4 in Equal ISI - Accuracy for SP4 in Decreasing ISI	-.722	11.651	2.746	-6.516	5.072	-.263	17	.796
Pair 5	Accuracy for SP5 in Equal ISI - Accuracy for SP5 in Decreasing ISI	.111	9.424	2.221	-4.575	4.798	.050	17	.961
Pair 6	Accuracy for SP6 in Equal ISI - Accuracy for SP6 in Decreasing ISI	.278	10.753	2.534	-5.069	5.625	.110	17	.914

Table 20 Paired samples t test comparing the means for accuracy of the different serial positions between decreasing ISI and equal ISI – Experiment 6

MATLAB codes for Experiment 1

Code for Temporal expansion

```
% Observed data 1 (replace this with your actual data)
observed_data1 = [0.4566666667, 0.3866666667, 0.38, 0.3266666667, 0.4733333333, 0.4333333333,
0.59]; % Example data
time_intervals1 = [0.15, 0.3, 0.6, 1.2, 2.4, 4.8, 9.6]; % Example TIV in seconds

% Observed data 2 (replace this with your actual data)
observed_data2 = [0.5233333333, 0.41, 0.46, 0.2933333333, 0.3166666667, 0.3733333333,
0.4866666667]; % Example data
time_intervals2 = [0.15, 0.3, 0.6, 1.2, 2.4, 4.8, 9.6]; % Example TIV in seconds

% Number of items for each dataset
nitems1 = length(observed_data1);
nitems2 = length(observed_data2);

% Initial guess for the parameters [c, slope, thresh] for both datasets
initial_params1 = [0.5, 20, 0.2];
initial_params2 = [0.5, 20, 0.2];

% Function to simulate SIMPLE model predictions
function predicted_data = simple_model(params, time_intervals, nitems)
    c = params(1);         % Distinctiveness parameter
    slope = params(2);      % Slope of the logistic function
    thresh = params(3);     % Threshold of the logistic function

    % Initialize distances and predicted data
    serpos = zeros(1, nitems);
    predicted_data = zeros(1, nitems);

    % Convert time intervals to log scale
    log_times = log(time_intervals);

    % Calculate distinctiveness for each item
    for n = 1:nitems
        sum_dist = 0;
        for m = 1:nitems
            if n ~= m
                sum_dist = sum_dist + exp(-c * abs(log_times(n) - log_times(m)));
            end
        end
        serpos(n) = 1 / sum_dist;
    end

    % Apply logistic function to calculate recall probabilities
    for n = 1:nitems
        predicted_data(n) = 1 / (1 + exp(-slope * (serpos(n) - thresh)));
    end
end

% Calculate the predicted data using the initial parameters for both datasets
predicted_data1 = simple_model(initial_params1, time_intervals1, nitems1);
predicted_data2 = simple_model(initial_params2, time_intervals2, nitems2);

% Define the cost function for the SIMPLE model for both datasets
simple_model_cost1 = @(params, observed_data, time_intervals, nitems) ...
    sum((simple_model(params, time_intervals, nitems) - observed_data).^2);
simple_model_cost2 = @(params, observed_data, time_intervals, nitems) ...
    sum((simple_model(params, time_intervals, nitems) - observed_data).^2);

% Use fminsearch to optimize the parameters for both datasets
```

```
fitted_params1 = fminsearch(@(params) simple_model_cost1(params, observed_data1,
time_intervals1, nitems1), initial_params1);
fitted_params2 = fminsearch(@(params) simple_model_cost2(params, observed_data2,
time_intervals2, nitems2), initial_params2);

% Get the fitted model data for both datasets
fitted_data1 = simple_model(fitted_params1, time_intervals1, nitems1);
fitted_data2 = simple_model(fitted_params2, time_intervals2, nitems2);

% Plot observed data vs fitted model for both datasets
figure;
plot(time_intervals1, observed_data1, 'bo-', 'LineWidth', 2, 'DisplayName', 'Observed Data 1');
hold on;
plot(time_intervals1, fitted_data1, 'r--', 'LineWidth', 2, 'DisplayName', 'Fitted Model 1');
plot(time_intervals2, observed_data2, 'gs-', 'LineWidth', 2, 'DisplayName', 'Observed Data 2');
plot(time_intervals2, fitted_data2, 'm--', 'LineWidth', 2, 'DisplayName', 'Fitted Model 2');
xlabel('Temporal Isolation Variable (s)');
ylabel('Frequency of Recall');
legend('Location', 'Best');
title('Free Recall Data Fit to SIMPLE Model for Two Datasets');
grid on;

% Adjust the limits of the x-axis and y-axis
xlim([0, 10]);  % Set the range of the x-axis
ylim([0, 1]);   % Set the range of the y-axis

hold off; % Release the plot

% Calculate and display performance metrics for both datasets
% For Dataset 1
mean_observed1 = mean(observed_data1);
SStot1 = sum((observed_data1 - mean_observed1).^2);
SSres1 = sum((observed_data1 - fitted_data1).^2);
R2_1 = 1 - (SSres1 / SStot1);
disp(['Dataset 1 R² value: ', num2str(R2_1)]);

% For Dataset 2
mean_observed2 = mean(observed_data2);
SStot2 = sum((observed_data2 - mean_observed2).^2);
SSres2 = sum((observed_data2 - fitted_data2).^2);
R2_2 = 1 - (SSres2 / SStot2);
disp(['Dataset 2 R² value: ', num2str(R2_2)]);
```

MATLAB codes for Experiment 1

Code for Temporal compression

```
% Observed data 1 (replace this with your actual data)
observed_data1 = [0.6966666667, 0.5566666667, 0.3933333333, 0.3833333333, 0.3066666667,
0.3666666667, 0.5433333333]; % Example data
time_intervals1 = [0.15, 0.3, 0.6, 1.2, 2.4, 4.8, 9.6]; % Example TIV in seconds

% Observed data 2 (replace this with your actual data)
observed_data2 = [0.3833333333, 0.22, 0.2166666667, 0.2033333333, 0.4166666667, 0.5033333333,
0.66]; % Example data
time_intervals2 = [0.15, 0.3, 0.6, 1.2, 2.4, 4.8, 9.6]; % Example TIV in seconds

% Number of items for each dataset
nitems1 = length(observed_data1);
nitems2 = length(observed_data2);

% Initial guess for the parameters [c, slope, thresh] for both datasets
initial_params1 = [0.5, 20, 0.2];
initial_params2 = [0.5, 20, 0.2];

% Function to simulate SIMPLE model predictions
function predicted_data = simple_model(params, time_intervals, nitems)
    c = params(1);         % Distinctiveness parameter
    slope = params(2);     % Slope of the logistic function
    thresh = params(3);    % Threshold of the logistic function

    % Initialize distances and predicted data
    serpos = zeros(1, nitems);
    predicted_data = zeros(1, nitems);

    % Convert time intervals to log scale
    log_times = log(time_intervals);

    % Calculate distinctiveness for each item
    for n = 1:nitems
        sum_dist = 0;
        for m = 1:nitems
            if n ~= m
                sum_dist = sum_dist + exp(-c * abs(log_times(n) - log_times(m)));
            end
        end
        serpos(n) = 1 / sum_dist;
    end

    % Apply logistic function to calculate recall probabilities
    for n = 1:nitems
        predicted_data(n) = 1 / (1 + exp(-slope * (serpos(n) - thresh)));
    end
end

% Calculate the predicted data using the initial parameters for both datasets
predicted_data1 = simple_model(initial_params1, time_intervals1, nitems1);
predicted_data2 = simple_model(initial_params2, time_intervals2, nitems2);

% Define the cost function for the SIMPLE model for both datasets
simple_model_cost1 = @(params, observed_data, time_intervals, nitems) ...
    sum((simple_model(params, time_intervals, nitems) - observed_data).^2);
simple_model_cost2 = @(params, observed_data, time_intervals, nitems) ...
    sum((simple_model(params, time_intervals, nitems) - observed_data).^2);

% Use fminsearch to optimize the parameters for both datasets
```

```
fitted_params1 = fminsearch(@(params) simple_model_cost1(params, observed_data1,
time_intervals1, nitems1), initial_params1);
fitted_params2 = fminsearch(@(params) simple_model_cost2(params, observed_data2,
time_intervals2, nitems2), initial_params2);

% Get the fitted model data for both datasets
fitted_data1 = simple_model(fitted_params1, time_intervals1, nitems1);
fitted_data2 = simple_model(fitted_params2, time_intervals2, nitems2);

% Plot observed data vs fitted model for both datasets
figure;
plot(time_intervals1, observed_data1, 'bo-', 'LineWidth', 2, 'DisplayName', 'Free Recall');
hold on;
plot(time_intervals1, fitted_data1, 'r--', 'LineWidth', 2, 'DisplayName', 'Fitted Model 1');
plot(time_intervals2, observed_data2, 'gs-', 'LineWidth', 2, 'DisplayName', 'Serial Recall');
plot(time_intervals2, fitted_data2, 'm--', 'LineWidth', 2, 'DisplayName', 'Fitted Model 2');
xlabel('Temporal Isolation Variable (s)');
ylabel('Frequency of Recall');
legend('Location', 'Best');
title('Free & Serial Recall Data Fit to SIMPLE Model for Decreasing ISI condition');
grid on;

% Adjust the limits of the x-axis and y-axis
xlim([0 10]); % Ensure the x-axis covers from 0 to 10

% Reverse the x-axis direction
set(gca, 'XDir', 'reverse');

ylim([0, 1]); % Force y-axis from 0 to 1
drawnow; % Ensure plot updates

hold off;

% Calculate and display performance metrics for both datasets
% For Dataset 1
mean_observed1 = mean(observed_data1);
SStot1 = sum((observed_data1 - mean_observed1).^2);
SSres1 = sum((observed_data1 - fitted_data1).^2);
R2_1 = 1 - (SSres1 / SStot1);
disp(['Dataset 1 R² value: ', num2str(R2_1)]);

% For Dataset 2
mean_observed2 = mean(observed_data2);
SStot2 = sum((observed_data2 - mean_observed2).^2);
SSres2 = sum((observed_data2 - fitted_data2).^2);
R2_2 = 1 - (SSres2 / SStot2);
disp(['Dataset 2 R² value: ', num2str(R2_2)]);
```

MATLAB codes for Experiment 2

Code for Temporal compression

```
% Observed data (replace this with your actual data)
observed_data = [0.3866666667, 0.35, 0.3766666667, 0.3866666667, 0.5333333333]; % Example data
time_intervals = [0.6, 1.2, 2.4, 4.8, 9.6]; % Example TIV in s

% Number of items for each dataset
nitems1 = length(observed_data1);

% Initial guess for the parameters [c, slope, thresh] for both datasets
initial_params1 = [0.5, 0, 0.2];

% Function to simulate SIMPLE model predictions
function predicted_data = simple_model(params, time_intervals, nitems)
    c = params(1);         % Distinctiveness parameter
    slope = params(2);      % Slope of the logistic function
    thresh = params(3);     % Threshold of the logistic function

    % Initialize distances and predicted data
    serpos = zeros(1, nitems);
    predicted_data = zeros(1, nitems);

    % Convert time intervals to log scale
    log_times = log(time_intervals);

    % Calculate distinctiveness for each item
    for n = 1:nitems
        sum_dist = 0;
        for m = 1:nitems
            if n ~= m
                sum_dist = sum_dist + exp(-c * abs(log_times(n) - log_times(m)));
            end
        end
        serpos(n) = 1 / sum_dist;
    end

    % Apply logistic function to calculate recall probabilities
    for n = 1:nitems
        predicted_data(n) = 1 / (1 + exp(-slope * (serpos(n) - thresh)));
    end
end

% Calculate the predicted data using the initial parameters for both datasets
predicted_data1 = simple_model(initial_params1, time_intervals1, nitems1);

% Define the cost function for the SIMPLE model for both datasets
simple_model_cost1 = @(params, observed_data, time_intervals, nitems) ...
    sum((simple_model(params, time_intervals, nitems) - observed_data).^2);


% Use fminsearch to optimize the parameters for both datasets
fitted_params1 = fminsearch(@(params) simple_model_cost1(params, observed_data1,
time_intervals1, nitems1), initial_params1);

% Get the fitted model data for both datasets
fitted_data1 = simple_model(fitted_params1, time_intervals1, nitems1);


% Plot observed data vs fitted model for both datasets
figure;
plot(time_intervals1, observed_data1, 'bo-', 'LineWidth', 2, 'DisplayName', 'Observed Data 1');
```

```
hold on;
plot(time_intervals1, fitted_data1, 'r--', 'LineWidth', 2, 'DisplayName', 'Fitted Model 1');
xlabel('Temporal Isolation Variable (s)');
ylabel('Frequency of Recall');
legend('Location', 'Best');
title('Total Recall Data Fit to SIMPLE Model');
grid on;

% Adjust the limits of the x-axis and y-axis
xlim([0 10]); % Ensure the x-axis covers from 0 to 10

% Reverse the x-axis direction
set(gca, 'XDir', 'reverse');

ylim([0, 1]); % Force y-axis from 0 to 1
drawnow; % Ensure plot updates

hold off;

% Calculate and display performance metrics for both datasets
% For Dataset 1
mean_observed1 = mean(observed_data1);
SStot1 = sum((observed_data1 - mean_observed1).^2);
SSres1 = sum((observed_data1 - fitted_data1).^2);
R2_1 = 1 - (SSres1 / SStot1);
disp(['Dataset 1 R² value: ', num2str(R2_1)]);
```