Investigating the maintenance of order information in manual-gestural serial recall: Effect of articulatory suppression and irrelevant sound

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A prominent view within the serial short-term memory literature is the notion of a functional equivalence for the maintenance of order information across the domains of immediate memory. Despite extensive research examining this for verbal, spatial, and, to some extent, visual material, there is a distinct lack of research into the maintenance of item order for manual gestures. As such, the current study aimed to rectify this by examining serial recall performance for manual gestures under varying conditions. Sequences were presented in silence, or in the presence of steady- or changing-state irrelevant sound. Furthermore, in one block of each experiment, articulatory suppression was employed. Serial position effects and relative recency were also examined for the secondary aim of investigating similarities in the encoding and processing of manual gestures. Experiment 1 made use of meaningless manual gestures, with results showing the presence of the changing-state effect which was subsequently eliminated by articulatory suppression. Articulatory suppression also significantly disrupted serial recall performance in all sound conditions. In Experiment 2, non-iconic gestures were used to reduce the potential for verbal recoding. In contrast to Experiment 1, the changing-state effect did not present, and while there was a main effect of articulatory suppression, corrected post-hoc tests revealed non-significant differences. While these results may suggest that participants relied on verbal recoding and subvocal rehearsal in Experiment 1, resulting in similarities to verbal serial recall, the mere ability of irrelevant sound and articulatory suppression to disrupt serial recall performance for manual gestures goes against the working memory model and points towards an amodal mechanism for the maintenance of serial order. As such, it is argued that the perceptual-gestural account is currently better suited to account for the observed effects.

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Chapter 1

Introduction

1.1 Overview

The importance of sequential organisation in many forms of human behaviour has been discussed at great length, from simple movements to more complex processes like the production of speech and acquisition of language (see e.g., Agam, Bullock, & Sekuler, 2005; Agam, Galperin, Gold, & Sekuler, 2007; Baddeley, 2007; Estes, 1985; Gupta, 2003; Lashley, 1951). While Lashley (1951) posed the question *"What then determines the order?"* (p. 117), the question asked today by many cognitive psychologists and memory researchers is *"What maintains the order?"*. To perform many human behaviours, one must be able to retain each element within an actionable sequence in the correct order, otherwise the integrity of the sequence is lost, and the action is performed incorrectly. For instance, imagine trying to remember a phone number long enough to write it down. Often, the digits which make up the number will be rehearsed subvocally in the order they were given. This process of subvocal rehearsal allows for sequences which contain strict order information to be maintained in that order, while also allowing for a more long-term representation of that information to be formed (Baddeley, Gathercole, & Papagno, 1998; Gathercole, Alloway, Willis, & Adams, 2006). A similar process could be used to remember a sequence of spatial items, such as locations on a map (see e.g., Tremblay, Parmentier, Guérard, Nicholls, & Jones, 2006) however, one area wherein very little is known regarding how order information is maintained relates to sequences of manual gestures (i.e., movements of the hands and/or arms).

A prominent view within the literature suggests that a single mechanism is responsible for the maintenance of order information, regardless of the perceptual nature of the input (e.g., verbal, spatial), i.e., a *functional equivalence* (see e.g., Jones, Farrand, Stuart, & Morris, 1995). Should this be the case, serial position curves and effects for manual-gestural serial recall should be akin to those observed with verbal and spatial material, with distractors and secondary tasks – such as irrelevant sound and articulatory suppression – resulting in similar levels of disruption (Jones et al., 1995). As such, the aim of the current study is to examine serial recall performance for sequences of manual gestures under various conditions; results from this study will be compared with previous research using verbal, spatial, and visual serial recall tasks in order to probe the suggestion of functional equivalence. First, it is essential to gain an understanding of the models and theories surrounding serial recall and the research which has attempted to elucidate how order information is maintained for verbal, spatial, and more recently, visual material.

1.2 The Working Memory Model

Currently, one way in which serial short-term memory (STM) is best understood is through the *working memory* (WM) model (see, Baddeley, 2000; Baddeley & Hitch, 1974). The WM model is a theory of memory proposed to account for the ability to store and manipulate information temporarily, which acts as a basis for all cognitive functions that require such storage and manipulation (see e.g., Hambrick, Kane, & Engle, 2005). It is based on the *multistore model* (Atkinson & Shiffrin, 1968), a unitary model of memory which Baddeley and Hitch argued was too simplistic, stating that different storage components were required for different types of information. As such, the initial WM model consisted of three components, two of which were stores for distinct forms of information. The *central executive* is responsible for the overall control of attention (i.e., directing WM resources), with two slave systems, the *visuospatial sketchpad* and the *phonological loop*, responsible for temporary storage and manipulation of visual-spatial and speech-based information respectively. Perhaps one of the most well-researched of these components is the phonological loop, made up of two subcomponents; the *phonological store* and an *articulatory rehearsal system*.

The role of the phonological store is to hold speech-based information in an abstract phonological form over short periods of time, with its primary function to generate a more long-term representation of that information, and a secondary function in supporting the short-term reproduction of verbal sequences (Baddeley et al., 1998; Gathercole et al., 2006). Memory traces within the store are prone to rapid decay (trace decay), which can occur within two seconds in the absence of rehearsal (see e.g., Repovs & Baddeley, 2006; Schweickert & Boruff, 1986), with one of the articulatory rehearsal systems two main functions being the facilitation of a rehearsal process to refresh items within the phonological store in order to prevent such decay from occurring (Baddeley, Thomson, & Buchanan, 1975). This rehearsal system has been described as analogous to a closed loop of inner speech (Baddeley, 1986), with this control process of subvocalisation also required for visual-verbal material to enter the phonological store – the second function of the articulatory rehearsal system. As auditory-verbal material is in phonological form when presented, it thus has direct and obligatory access to the phonological store, whereas visual-verbal material must undergo a grapheme-to-phoneme conversion process in order to gain access (i.e., phonological coding; Baddeley, 2003, see, Leinenger, 2014 for a comprehensive review of phonological coding).

As the WM model reflects temporary storage and manipulation, it is concerned with active processes that an individual may be undertaking. If we take the example of trying to remember a phone number, in most instances, an individual possesses the ability to direct attention to remembering the number in order to utilise WM resources to complete the task. This is not to say that WM does not have limits; it is indeed held to be a capacity-limited system, with performance on tasks that utilise WM resources limited to the amount of information which can be stored temporarily (e.g., Baddeley et al., 1975). Furthermore, while some tasks can be completed simultaneously, there are others which compete for WM resources, thus interfering with each other and causing reduced task performance (e.g., Richardson & Baddeley, 1975).

While the interaction between the phonological store and articulatory rehearsal system was able to account for a number of serial recall phenomena (e.g., phonological similarity, irrelevant speech, and word length effects; see e.g., Baddeley, 1986), there were a number of criticisms of the WM model. Perhaps one of the most substantial criticisms was that the model did not account for any relationship between long-term memory (LTM) and WM, and, as a result, the model was revised. Baddeley (2000) added a fourth component, the *episodic buffer*, which provided a number of additional features to the model. Here, provision was made to link WM and LTM by the addition of a mechanism through which information from other components of WM could be collated into a unitary representation. The addition of the episodic buffer also provided extra storage space which was independent of the perceptual nature of the information, meaning that items held in the other components of WM could be bound with semantic and linguistic knowledge held in LTM to create an 'episode' which is then held in a 'multidimensional' code (Baddeley & Wilson, 2002). In the context of manual gestures, particularly with regard to sign language, the episodic buffer would facilitate the amalgamation of visual and spatial information obtained from the movement itself, which enables semantic information to be drawn from LTM, allowing the viewer to recognise the movement and its meaning.

It should also be highlighted that the functioning of the phonological loop has been modelled in terms of the *primacy model* (Page & Norris, 1998). This model makes a number of assumptions; items are represented as activated nodes with the assumption that the first item in a sequence has maximal activation and a further assumption that activation decreases with each item in the sequence, resulting in a *primacy gradient*. Retrieval of an item is carried out by a process called *competitive cueing*, wherein the item with the strongest activation will be selected for recall. Additionally, it is assumed that once an item has been recalled, it is suppressed and therefore is not available to be recalled again (see, Lewandowsky & Farrell, 2008). In general terms, this model stores the order of items within a sequence based on the assumption that for each successive item within a list, activation strength decreases, i.e., an item in serial position one will have a greater activation strength than an item in serial position two, an item in serial position two will have a greater activation strength than an item in serial position three, and so on. Thus, based on the primacy model, serial recall performance is expected to deteriorate as a result of time-based decay, with the duration between presentation and commencement of recall of a sequence dictating the strength of the primacy gradient, as evident from the word- and list-length effects observed within Page and Norris (1998).

1.3 The Perceptual-gestural Account

The WM model has been accepted as the 'standard' account of serial STM for a significant time however, in recent years, a new and alternative view has been developed; the *perceptual-gestural account* (see, Hughes, Chamberland, Tremblay, & Jones, 2016; Hughes & Marsh, 2017; Hughes, Marsh, & Jones, 2009; Jones, Hughes, & Macken, 2006, 2007; Jones, Macken, & Nicholls, 2004; Macken & Jones, 2003). This account posits that general-purpose perceptual input and motor output processes that are considered as peripheral in phonological store-based models, are manipulated in an 'on-the-fly' manner in order to meet the demands of a task (Hughes et al., 2016). In general terms, serial recall makes use of general-purpose vocal-motor processes in order to retain the order of a presented sequence. Thus, the basis of the account is the interplay of perceptual and vocal-motor processes however, there is the potential for this to be extended to include manual gestures, as it has been for oculomotor processes (see e.g., Guérard & Tremblay, 2011). While this 'parasitic' view of serial recall has been suggested in some capacity by others (e.g., Buchsbaum & D'Esposito, 2008; Reisberg, Rappaport, & O'Shaughnessy, 1984), the perceptual-gestural account is the first to fully flesh out the concept. On the WM model, it is postulated that the process of articulatory rehearsal is in service to the revivification of decaying memory traces within the phonological store and/or the conversion of graphemes to phonemes in the case of visual-verbal material. However, the perceptual-gestural view is that articulatory rehearsal binds the individual items within a sequence into a single motor object (Hughes et al., 2016). This binding also provides a surrogate set of paralinguistic speech habits which replace information (e.g., semantic) that has been intentionally stripped from serial recall sequences, aiding constraint of item order and providing sequentiality (Hughes et al., 2009).

1.4 Disruption of Short-term Memory

The way in which the maintenance of item order in STM has been investigated is through the use of *immediate serial recall* (ISR) tasks, wherein a participant is required to reproduce a sequence of items (e.g., permutations of the digits 1-7, or locations of dots on a screen) in the order they were presented. A large number of studies have also employed articulatory suppression and to-be-ignored (TBI) irrelevant sound in order to examine the extent to which these can interfere with serial recall performance (e.g., Baddeley, Lewis, & Vallar, 1984; Colle, 1980; Colle & Welsh, 1976; Elliott, 2002; Jones et al., 1995; Jones & Macken, 1993; Jones, Macken, & Murray, 1993; Levy, 1971; Morris, Quayle, & Jones, 1989; Murray, 1968; Salamé & Baddeley, 1982). In a recent paper by Oberauer et al. (2018), a set of benchmarks were proposed as a starting point for models of STM. These benchmarks are a number of well-replicated phenomena, including the irrelevant sound and articulatory suppression effects, that the authors suggest STM models should be evaluated against in the initial stages, with the view that these will become *"common empirical constraints for competing theories and models"* (Oberauer et al., 2018, p.5). Thus, on the basis of the paper by Oberauer and colleagues, in order for a new model of STM to gain any degree of validity, it should be able to account for these phenomena.

1.5 Articulatory Suppression

Articulatory suppression refers to the overt articulation of an irrelevant item (e.g., "the, the, the...") or irrelevant items (e.g., "A, B, C...") by participants during a task (Baddeley et al., 1984; Levy, 1971; Murray, 1968). On the WM model, it is believed that articulatory suppression impedes the ability of the articulatory rehearsal system to revivify decaying memory traces held within the phonological store. Additionally, it is believed that articulatory suppression prevents visual-verbal material from undergoing the grapheme-to-phoneme conversion process it requires to enter the phonological store. While auditory-verbal information is in phonological form when presented, thus giving it direct access to the store, visual-verbal material must be converted however, as the articulatory rehearsal system is engaged with suppression, this conversion cannot occur (Baddeley, 2003). As such, when articulatory suppression is employed in a task such as ISR, performance is reduced due to the failure of two fundamental processes within the phonological loop; information within the store cannot be rehearsed resulting in its decay, and new visual-verbal information cannot be converted and thus, cannot enter the store (Baddeley, 1986; Baddeley et al., 1984; Macken & Jones, 1995; Nairne, 1990).

With regard to the Primacy Model (Page & Norris, 1998), the (assumed) prevention of subvocal rehearsal by articulatory suppression has a noticeable effect on the strength of the primacy gradient. When subvocal rehearsal is permitted, the strength of the primacy gradient upon recall is not dependant on the commencement of list presentation, but rather on the most recent rehearsal of the sequence. As such, the time between rehearsal and recall is reduced, strengthening the gradient. However, the employment of articulatory suppression to prevent the use of subvocal rehearsal results in a reduced primacy gradient as the time between presentation and recall is increased.

In terms of spatial recall, the analogue of articulatory suppression is tapping (e.g., tapping on a desk or tapping keys on a keyboard). Despite findings from Jones et al. (1995) showing that articulatory suppression and tapping result in comparable levels of disruption for both verbal and spatial serial recall, it is widely accepted that there are crossover effects, with articulatory suppression disrupting verbal serial recall to a greater extent than spatial serial recall and tapping disrupting spatial serial recall to a greater extent than verbal serial recall (see e.g., Guérard & Tremblay, 2008; Meiser & Klauer, 1999). Additionally, it has also been shown that both articulatory suppression and tapping disrupt serial recall for visual material (see, Smyth, Hay, Hitch, & Horton, 2005, see also, Section 1.11).

1.6 The Irrelevant Sound Effect

During initial investigation of the effect of irrelevant sound on serial recall performance, speech was used as the TBI background sound, hence the phenomenon was first known as the irrelevant *speech* effect. During presentation of the to-be-remembered (TBR) items, a repeated speech token (e.g., "A, A, A...") or changing sequence of tokens (e.g., "A, B, C...") is played in the background, with participants instructed to ignore this. Typically, serial recall performance is disrupted in the presence of this background speech (e.g., Colle, 1980; Colle & Welsh, 1976; Morris et al., 1989; Salamé & Baddeley, 1982), with some suggesting, based on the WM model, that disruption occurs as a result of interfering phonemes within the phonological store, with the degree of similarity between phonemes in the TBR and auditory streams influencing the magnitude of this disruption (i.e., *interference-by-content*; e.g., Burgess & Hitch, 1992; Gathercole & Baddeley, 1993; Salamé & Baddeley, 1982). Interestingly, the general view that disruption of serial recall by irrelevant speech is due to interference is also adopted by those favouring the *feature model* (Nairne, 1990) however, the mechanism of interference differs (see, Neath, 2000, for the account of interference according to the feature model).

Based on findings which had shown that broadband noise produced little, or indeed, no disruption, it had been suggested that disruption of serial recall performance only occurs when speech is used as the irrelevant auditory stimuli (e.g., Salamé & Baddeley, 1982, 1989). This claim was later refuted by studies which found that non-speech sounds could elicit the same effect (e.g., Elliott, 2002; Jones & Macken, 1993), thus, the phenomenon was renamed the irrelevant *sound* effect (Beaman & Jones, 1997). While Salamé and Baddeley (1982, 1989) utilised a steady, continuous broadband sound, it was later found that an important characteristic of the disruption of serial recall performance by irrelevant auditory stimuli was the *changing* nature of the irrelevant material and not its content (Jones, Madden, & Miles, 1992). Results from a number of studies showed that repetition of a single irrelevant sound did not always cause significant disruption of performance however, performance *was* significantly disrupted in the presence of a changing sequence of irrelevant sounds (e.g., Jones & Macken, 1993; Jones et al., 1993), termed the *changing-state effect*. Specifically, the changes within a sequence of irrelevant items can refer to a number of different characteristics, for example, each item having a distinct pitch or timbre, which has been shown to disrupt serial recall performance (e.g., Jones, Macken, & Harries, 1997).

1.7 Towards a Functional Equivalence in Short-term Memory

The finding that a changing sequence of irrelevant auditory tokens disrupted serial recall performance to a greater extent than a repeated irrelevant token led to the development of the *changing-state hypothesis* (Jones & Macken, 1993; Jones et al., 1992). This suggests that disruption of serial recall performance due to irrelevant sound occurs not as a result of interference due to similarity of the TBR and TBI items, but rather due to interference between two simultaneous processes that maintain item order for both sets of stimuli. Even though the auditory items are irrelevant to the task, each change in auditory token generates order cues as a result of preattentive streaming (see, Bregman, 1990). Consequently, when rehearsal is employed to maintain serial order for the TBR items, the order cues for the irrelevant changing-state sequence are processed obligatorily. These order cues then vie for inclusion in the formation and maintenance of the motor-plan utilised to retain the order of the TBR sequence, with this resulting in reduced serial recall performance i.e., *interference-by-process* (see, Hughes, Hurlstone, Marsh, Vachon, & Jones, 2013; Hughes, Vachon, & Jones, 2005, 2007), thus demonstrating that non-speech sounds have the potential to disrupt serial recall performance.

Evidence to support the view that disruption of performance is due to interfering processes rather than similarity of the TBR and TBI content can be found in studies that have manipulated the perceptual organisation of the irrelevant sequences. For example, Jones and Macken (1995) presented the same changing irrelevant sequence ("X, Y, Z") monoaurally, that is to say, emanating from one source (the centre), which resulted in significant disruption of serial recall performance. Conversely, assigning each item within the same changing irrelevant sequence to a different location (e.g., "X" to the left ear, "Y" to the right ear, and "Z" to the centre), reduced the degree to which serial recall performance is disrupted (Jones & Macken, 1993, 1995; Jones, Saint-Aubin, & Tremblay, 1999). Note that while perceptual organisation was manipulated, the content within the TBR and TBI sequences remained the same. It has been suggested that this reduction in disruption of serial recall performance is due to the irrelevant sequence no longer conforming to the conditions required for changing-state; the partition of items within the sequence to different locations leads to three steady-state streams, thus resulting in reduced disruption (Macken, Tremblay, Houghton, Nicholls, & Jones, 2003, see also, Bregman, 1990).

Additionally, the effect of irrelevant sound and articulatory suppression has been investigated for lipread sequences. In a series of experiments, Divin, Coyle, and James (2001) found that irrelevant sound was able to disrupt sequences of lipread digits, supporting results from previous studies (Campbell & Dodd, 1984; Jones, 1994). However, upon addition of articulatory suppression, the disruption of recall by irrelevant sound was eliminated. In a further experiment, the authors found that irrelevant speech and tones that varied in frequency disrupted recall of lipread sequences to an equal extent, providing further support for the changing-state hypothesis. As stated previously, those favouring the WM model suggest that speech should be more disruptive than tones (e.g., Salamé & Baddeley, 1982, 1989) however, these results clearly support the view of the changing-state hypothesis in that it is the changing nature of the irrelevant sound which dictates disruption of recall.

Other evidence to support the changing-state hypothesis can be found in studies which examined the effects of phonological similarity, irrelevant sound, articulatory suppression, and task type. Several studies investigated the influence of phonological similarity – the phenomenon wherein similar 'sounding' items (e.g., B, V, C) within the TBR and TBI sequences result in greater disruption of serial recall than items which do not 'sound' similar (e.g., X, M, L; see, Conrad, 1964) (e.g., Jones & Macken, 1993, 1995; LeCompte & Shaibe, 1997; Martin-Loeches, Schweinberger, & Sommer, 1997). It was found that phonological similarity between the two streams of information did not mediate the degree to which serial recall is disrupted by irrelevant sound, providing evidence contrary to a key empirical signature of the phonological store. On the WM model, it was initially postulated that as irrelevant speech gains obligatory access to the phonological store wherein it can interfere with memory traces of TBR items, phonological similarity between the TBR and TBI items would mediate the degree of disruption (Salamé & Baddeley, 1982), a view contradicted by the aforementioned studies.

The finding that disruption of serial recall is not mediated by the phonological similarity of the TBR and TBI sequences goes against a central, theoretical tenet of the WM model which proposes that it is the action of dedicated memory stores (i.e., the phonological loop and visuospatial sketchpad) that give rise to storage functions within WM (see, Postle, 2006). However, if the similarity between the TBR and TBI items does not determine serial recall performance, it is difficult to invoke these storage mechanisms. Furthermore, Macken and Jones (1995) investigated a prediction of the *Object-Oriented Episodic Record* (O-OER) model, a precursor of the perceptual-gestural account (see, Jones et al., 1993, see also, Hughes et al., 2005, 2007), which suggested that articulatory suppression would also give rise to a changing-state effect, with results showing that suppression during serial recall did indeed produce a changing-state effect for articulatory suppression, akin to that observed with irrelevant auditory material. Additionally, the authors found that the changing-state effect for articulatory material was only found in tasks that require the retention of serial order, with further support for this provided by later studies (e.g., Beaman & Jones, 1997, 1998).

As stated previously, the primacy model (Page & Norris, 1998) suggests that the storage of items within a sequence is based on a primacy gradient, wherein recall performance of a sequence deteriorates as a function of list position. As such, should changing-state irrelevant sound be added to a serial recall task, the order of the irrelevant auditory sequence would be based on a primacy gradient similar to that of the TBR material. Thus, this would suggest, on the primacy model, that any disruption as a result of irrelevant sound occurs due to interference-by-process, as the order of items within the TBR and TBI sequences is being maintained by the same mechanism. With regard to verbal serial recall tasks, wherein phonological similarity between TBR and TBI items could affect performance, the primacy model states that this occurs at a stage after (and thus, distinct from) the ordering stage (see, Lewandowsky & Farrell, 2008; Page & Norris, 1998). Taken together, these studies provide evidence to support the changing-state hypothesis, as well as the interference-by-process account, with Macken and Jones (1995) also suggesting a functional equivalence between codes from auditory, articulatory, and visual origins.

1.8 The Visuospatial Sketchpad

Prior to discussing research which has examined serial recall for spatial items, it is important to highlight the mechanism within the WM model concerned with storage and manipulation of visual-spatial information – the visuospatial sketchpad (Baddeley & Hitch, 1974). While this component deals with both visual and spatial information, it has been suggested by some (e.g., Vicari, Bellucci, & Carlesimo, 2006) that there are distinct subcomponents which deal with each type of input. In Logie's (1995) model of working memory, it was proposed that visual information (e.g., colour) was stored in a *visual cache*, with spatial material being stored by an *inner scribe*. Material held within the visuospatial sketchpad, like that held in the phonological store, is prone to decay unless rehearsed, with Logie (1995) suggesting that the inner scribe facilitates this rehearsal. Rehearsal of spatial material is believed to be facilitated by a spatial-attention mechanism, wherein attention shifts to the target area, with studies utilising eye-tracking corroborating this view (see, Awh & Jonides, 2001; Awh, Vogel, & Oh, 2006; Postle, Druzgal, & D'Esposito, 2003; Tremblay, Saint-Aubin, & Jalbert, 2006). Note that while interference to this rehearsal mechanism in spatial tasks has been shown to disrupt performance, use of visual tasks – devoid of a spatial component – no effect of interference has been observed (see e.g., Cocchini, Logie, Sala, MacPherson, & Baddeley, 2002).

1.9 Jones, Farrand, Stuart, and Morris (1995) and Replication Attempts

The suggestion of functional equivalence between codes implies the existence of an amodal mechanism for the representation of order in serial recall for all perceptual modalities (e.g., verbal, visual, spatial). Perhaps one of the most important studies that examined this notion of functional equivalence was conducted by Jones et al. (1995). In a series of experiments, the authors investigated the effects of irrelevant sound and articulatory suppression on spatial serial recall performance, comparing results with performance on verbal serial recall tasks. Based on the findings from studies investigating the changing-state hypothesis, it was postulated that analogous effects would be observed in serial recall for spatial material. While Jones et al. (1995) do provide evidence in support of this view, not all of the findings from this study have been replicated in a number of attempts (e.g., Guérard & Tremblay, 2008; Guitard & Saint-Aubin, 2015; Kvetnaya, 2018; Meiser & Klauer, 1999).

Experiment 1 of Jones et al. (1995) showed that serial recall for spatial items (sequences of dots presented in different locations on a screen) displayed similar characteristics to that of verbal serial recall, with both primacy and recency effects – the finding that the first and last items respectively, are better remembered than those in the middle – as well as improved performance as a result of rehearsal and greater error with longer sequence lengths. The authors state that this alone provides a degree of evidence to support the notion of a functional equivalence between verbal and spatial serial recall performance, with Guérard and Tremblay (2008) replicating the effects. Furthermore, a number of other studies that also utilised spatial serial recall tasks found serial position effects akin to those observed in verbal serial recall (Avons, 2007; Farrand, Parmentier, & Jones, 2001; Tremblay, Saint-Aubin, & Jalbert, 2006).

Experiments 2 and 3 of Jones et al. (1995) also provide support for the notion of a functional equivalence through investigation of the interference of a spatial-manual task (Experiment 2; tapping either one key or multiple keys on a keyboard) and articulatory suppression (Experiment 3), on both verbal and spatial serial recall. Findings from Experiment 2 show that the changing-state spatial-manual task (tapping multiple keys), results in comparable levels of disruption for both verbal and spatial serial recall. In Experiment 3, a similar pattern of results was found, with disruption of serial recall by articulatory suppression the same order of magnitude for both verbal and spatial items. These results clearly contradict the view of the WM model which suggests that disruption of serial recall is due to both the primary and secondary tasks utilising the same WM resources (e.g., spatial primary and secondary tasks which both utilise the visuospatial sketchpad). However, in two replication attempts of these experiments, it was found that performance on the spatial serial recall task was disrupted to a greater extent than the verbal serial recall task when the same spatial-manual task was carried out simultaneously (Guérard & Tremblay, 2008; Meiser & Klauer, 1999). Furthermore, these studies also found no effect of articulatory suppression on both verbal and spatial serial recall performance, with Guitard and Saint-Aubin (2015) also showing no difference between steady- and changing-state suppression.

Experiment 4 of Jones et al. (1995) examined the extent to which both steady- and changing-state irrelevant sound (in this instance, either repetition of the syllable "Ah" or the letters A through G) disrupted both verbal and spatial serial recall. Results show that the irrelevant sound was able to disrupt both verbal and spatial serial recall performance, with significant differences between steady- and changing-state irrelevant sound found in each task i.e., a changing-state effect for both verbal and spatial sequences. The authors suggest that the mere presence of disruption of performance on spatial serial recall by irrelevant sound provides robust support for the interference-by-process account however, a recent replication attempt of this experiment by Kvetnaya (2018), failed to find an effect of sound type, with a further replication conducted by our lab also failing to find an effect (Marsh et al., unpublished data).

It is possible that the inability to replicate the findings from Experiment 4 is simply due to the sample size of the original study. A between-participants design was used, with 18 participants taking part in each experimental condition (verbal and spatial serial recall), in contrast with Kvetnaya (2018), wherein a within-participants design was used (only spatial serial recall was investigated), with 40 participants. The overall failure to replicate the findings of Jones et al. (1995) by no means suggests that the notion of an amodal mechanism for the maintenance of item order across perceptual modalities should be abandoned altogether. Indeed, there is evidence from other areas of research that provides support for this view (e.g., Avons, 1998; Farrand & Jones, 1996; Smyth et al., 2005; Smyth & Scholey, 1996).

1.10 Evidence from Visual Short-term Memory

Visual STM is a capacity-limited system that allows for the temporary storage of visual information necessary to complete a task (Phillips, 1974). This memory system is distinct from iconic memory in that it has a longer duration, with most regarding iconic memory as simply being the very brief perseverance of the original image (Neisser, 1967; Sperling, 1960). It was initially believed that in order for visual information to be held for a longer duration than iconic memory, verbal recoding was being employed (e.g., Sperling, 1963, 1967) however, this theory can be attributed to the characteristics of the tasks used during initial investigation of visual STM which required either vocalised or written verbal responses (e.g., Brener, 1940; Sperling, 1960). In recent years, the capacity limitation of visual STM has been the subject of increased discussion, with some suggesting that this is determined by how many items can be held in STM, how many features can be remembered, or a function of both (see e.g., Lee & Ahn, 2013; Luck & Vogel, 2013; Sewell, Lilburn, & Smith, 2014, 2018). Within the WM model, the visuospatial sketchpad is responsible for the storage and manipulation of visual information (see, Section 1.8). An aspect of visual STM which can inform the current research is that of serial recall performance for sequences of faces.

1.11 Serial Recall for Faces

Some investigations of visual serial recall performance utilised novel patterns/matrices (e.g., Avons, 1998; Phillips & Christie, 1977) however, as stated by Smyth et al. (2005), there are a number of limitations when using this form of stimuli. In verbal serial recall tasks, stimuli are usually formed from a familiar set of items (e.g., digits, letters) however, the patterns and matrices used in visual serial recall studies are unfamiliar, thus potentially resulting in excessive encoding demands and subsequent effects on serial position. Furthermore, while 'nonsense' items in the verbal domain (e.g., non-words) can be used to assess serial recall performance, these often follow a linguistic structure which can aid in the encoding process. Conversely, there is no such familiar structure for novel patterns and matrices that can assist with their encoding, meaning that results from studies using this type of stimuli should be interpreted with a degree of caution. Smyth et al. (2005) sought to overcome this issue by using faces as the stimuli, providing a number of characteristics well-suited for serial recall. For example, while the basic features of faces are the same, an unlimited number of stimuli can be generated, as well as the ability to manipulate similarity. Furthermore, it has been shown that ones ability to verbally recode faces is limited, even when recoding is encouraged (see, Chin & Schooler, 2008).

In two experiments, Smyth et al. (2005) presented images of unfamiliar faces with participants required to reproduce the order the faces were presented. Three conditions were used; no concurrent task, articulatory suppression, and spatial tapping, with four set sizes (3, 4, 5, and 6 faces). Results from Experiment 1 show that serial recall performance was similar to that observed in verbal serial recall, with results from Experiment 2 showing that order reconstruction after a longer retention period (6s) was comparable to that of a shorter retention period (2s). Additionally, it was found that while visual similarity, articulatory suppression, and spatial tapping affected serial recall independently, articulatory suppression did not interact with similarity in both experiments, leading to the conclusion that participants were not relying on verbal recoding. It should be noted that while articulatory suppression and spatial tapping both disrupted serial recall performance, articulatory suppression was more disruptive. The general scarcity of interactions with articulatory suppression led the authors to suggest that the *similarities* between verbal serial recall and the results obtained in these experiments were not due to verbal recoding or subvocal rehearsal, stating that these findings add to the idea that subvocal rehearsal may not be a precondition for serial position effects to arise. The authors conclude that the lack of substantial *differences* between verbal and non-verbal serial recall performance suggest maintenance of order information in serial recall is facilitated by either a domain-general mechanism, or domain-specific mechanisms which exude similar characteristics due to their performance of the same process.

1.12 Movement in Short-term Memory

Based on the research discussed previously, there appears to be some evidence in favour of an amodal mechanism responsible for the maintenance of item order across perceptual modalities however, this view has not yet been examined in the context of manual gestures. There has been some suggestion of a third subcomponent within the visuospatial sketchpad which can hold action sequences in a kinaesthetic code (e.g., Baddeley, 1983, 2007; Smyth, Pearson, & Pendleton, 1988; Smyth & Pendleton, 1989). For example, Smyth et al. (1988) found that serial recall performance for movements was disrupted by a secondary task involving sizeable arm movements, but not by a secondary task involving movements to specific spatial targets. The authors suggest that this provides evidence for a rehearsal mechanism for body movements that is distinct from spatial rehearsal. However, as stated by Smyth and Pendleton (1989), whole-body movements were compared with hand movements to spatial targets, with this difference potentially being the important factor rather than the nature of the movements (i.e., spatial vs. configured; cf. Rudner, 2015). Interestingly, one aspect of this research suggests that motor processes are involved in the manipulation of spatial information (see also, Logie, 1986; Quinn & Ralston, 1986), which harmonises with the view proposed by the perceptual-gestural account. Indeed, there is evidence to support this, with some research examining the potential for an 'articulatory' loop-like mechanism for movements, facilitated by motoric (and sensory) processes (see, Wilson & Fox, 2007).

1.13 An 'Articulatory' Loop for Movement?

While there has been a substantial amount of research surrounding the mechanisms that facilitate verbal STM and to a lesser extent, visual-spatial STM, there is a distinct lack of research examining similar mechanisms in the context of manual gestures. One area in which there is some research involves the use of sign language as stimuli. Like spoken languages, signed languages exhibit a structure wherein components of the language which would otherwise be meaningless, can contain meaningful information (see, Emmorey, 2007; Emmorey, McCullough, Mehta, & Grabowski, 2014); in other words, the lexicon of signed languages is made up of 'random' manual movements which, when structured, are associated with semantic information. However, this is not to say that signed and spoken languages do not have 'iconic' lexical items (see, Baus, Carreiras, & Emmorey, 2013). Furthermore, several studies have found that effects akin to phonological similarity, articulatory suppression, and word-length – all signatures of the phonological loop – presented with American Sign Language, which suggests that speech is not unique and that a mechanism similar to that of the phonological loop may facilitate STM for movement, and potentially distinct forms of information that are not solely verbal (see, Wilson & Fox, 2007). This view corresponds with a suggestion by Smyth et al. (2005); they state that while various computational models of verbal serial recall (e.g., Brown, Preece, & Hulme, 2000; Burgess & Hitch, 1999; Henson, 1998; Page & Norris, 1998) are based on the framework of the phonological loop, there are parts within these models such as the context signals contained in the models proposed by Brown et al. (2000) and Burgess and Hitch (1999), that could be linked to non-verbal material.

Evidence to support this view can be found in Wilson and Fox (2007), who questioned whether language was a necessary precondition for the development of an 'articulatory' loop for non-verbal material. In order to investigate this, they used a serial recall task with meaningless manual gestures that followed the phonological structure of sign language as the stimuli. Results from this study show effects of 'phonological' similarity, 'articulatory' suppression, and 'word'-length, leading the authors to suggest that a sensorimotor mechanism akin to that of the phonological loop can be formed 'on-the-fly' in order to meet the demands of the task. Later research by Rudner (2015) investigated whether similarity in the formation of meaningless manual gestures can influence performance; this was based on the gestures within Wilson and Fox (2007) following the phonological structure of sign language, thus allowing for categorisation of the gestures which may influence performance as a result of linguistic similarities held in LTM. Results from this study show that manual gestures with no linguistic representation in LTM (catching a ball in this instance), can be stored and manipulated in STM, with performance in an N-back task disrupted by increases in memory load and by use of spatially similar non-target manual gestures. This not only supports the previous work by Wilson and Fox (2007) but also highlights the potential of visual similarity effects in sign language.

1.14 The Modality Effect

One strand of research which may prove fruitful in investigating not only how gestures are encoded and processed in STM, but also the notion of a functional equivalence between memory domains, relates to modality. With regard to the verbal domain, it has been a long-held view that linguistic information acquired from both auditory and visual modalities is stored in an abstract phonological form, distinct from perceptual input and motor output processes (e.g., Baddeley, 2000; Baddeley & Hitch, 1974). Those adopting this view attribute observed differences in modalities to modality-specific features such as encoding, while storage and manipulation of the common, phonological representation of all information, is responsible for any observed similarities. However, there is contrasting evidence to suggest that modality-specific perceptual input and motor output processes play a more central role in verbal STM than phonological store-based models of memory would suggest (see e.g., Maidment & Macken, 2012; Maidment, Macken, & Jones, 2013).

The notion that verbal material garnered from auditory and visual modalities obtains the same phonological representation has been investigated through the examination of serial recall performance for auditory and silently lipread items. Previous research has shown that serial recall performance is enhanced for the final item within an auditory sequence when compared to a visual sequence, termed the *modality effect* (see e.g., Crowder & Morton, 1969; Frankish, 1996; Penney, 1989; Surprenant, Pitt, & Crowder, 1993). It should also be noted that more recent studies have also shown similar effects with visual and spatial material. For example, Tremblay et al. (2006, Experiment 2) equated visual-spatial, visual-verbal, auditory-spatial, and auditory-verbal sequences on the basis of order reconstruction. Results show not only the manifestation of the classical modality effect, but also a modality effect for auditory-spatial sequences (see also, Avons, 1998; Farrand & Jones, 1996; Nairne & Dutta, 1992; Smyth et al., 2005; Smyth & Scholey, 1996).

Regarding silently lipread sequences, studies have shown that these gain the same final item recall advantage as auditory sequences (e.g., Campbell & Dodd, 1980), with the addition of a redundant suffix of the same modality at the end of a sequence negating this enhanced performance for both auditory and silently lipread sequences, termed the *suffix effect* (see, Campbell & Dodd, 1982). Furthermore, it has also been shown that an auditory suffix at the end of a silently lipread sequence will disrupt the enhanced recall of the final item, with a silently lipread suffix at the end of an auditory sequence having the same outcome (however, cf. Maidment et al., 2013).

Thus, it appears that silently lipread sequences behave in much the same manner as auditory sequences, both with regard to the modality effect and the effects of irrelevant sound and articulatory suppression as discussed previously (see, Section 1.7). Therefore, this could provide a framework from which to begin investigating the way in which gestures are encoded and processed in STM. The presence of a modality effect for manual gestures, paired with disruption of serial recall performance by irrelevant sound, which is subsequently eliminated under articulatory suppression, could lead to the suggestion that manual gestures are encoded in a manner similar to that of auditory or lipread items.

1.15 The Current Study

The most important aspect of the research discussed previously comes from results that suggest an amodal mechanism is responsible for the maintenance of order information across perceptual modalities. This is at odds with the WM model which states that distinct components within the model are responsible for the storage and maintenance of specific types of information (e.g., Baddeley & Hitch, 1974), while simultaneously providing support for the perceptual-gestural account which posits that general-purpose perceptual input and motor output processes are co-opted in order to meet the demands of a task (e.g., Hughes et al., 2016). In order to fully elucidate the way in which order information is maintained in STM, it is important to determine this for other forms of material, such as manual gestures. It is important to note at this point that in this study 'manual gestures' refer to gestures that do not accompany speech (see e.g., McNeill, 1992), with Experiment 1 making use of meaningless manual gestures and Experiment 2 using non-iconic manual gestures.

Thus, the current study will assess serial recall performance for manual gestures with steady- and changing-state irrelevant sound used to investigate whether the changing-state effect presents with manual gestures. Articulatory suppression will also be used in order to minimise the potential for participants to verbally recode the manual gestures. In addition, a relative recency measure will be employed in an attempt to investigate the manner in which manual gestures are encoded. On the basis of previous research, it is hypothesised that irrelevant sound will have a disruptive effect on recall, with changing-state irrelevant sound being more disruptive than steady-state irrelevant sound i.e., the changing-state effect. Additionally, it is hypothesised that articulatory suppression will also disrupt recall, with the effect of changing-state eliminated under suppression. With regard to the secondary aim of the study, it is difficult to speculate whether similar serial position effects will present with manual gestures, particularly given the use of relative recency over the 'traditional' measure of recency. As previous research has shown, both auditory and lipread sequences gain a final item recall advantage (see, Sections 1.7 & 1.14) however, this has not yet been investigated for manual gestures therefore, it remains to be seen if relative recency measures will provide insight in this regard.

Chapter 2

Experiment 1

2.1 Overview

This experiment will utilise sequences of meaningless manual gestures in order to examine the maintenance of order information for movements. One of the major issues with achieving this is equating the serial recall task to those found in other domains of memory with Avons (1998) suggesting that should serial recall tasks be equated, similar serial position effects will be observed, including the characteristic bow-shaped serial position curve. Thus, the extent to which the task used in the current experiment is equated to other serial recall tasks will be based on the shape of the serial position curves.

2.2 Method

Participants, Design, and Ethics

Thirty-three (33) participants (female; $N = 23$; age; $M = 22.63$, $SD = 4.17$; Appendix 1) consented (Appendix 2) to take part in this study. All participants had normal or corrected-to-normal visual acuity and hearing. Participants were awarded a small honorarium for taking part. A within-participant design was used, with all participants completing all aspects of the task.

Serial Recall Task

This experiment utilised a simple serial recall task, wherein sequences of videos depicting meaningless manual gestures were used (see, Wu & Coulson, 2014, for full repository of videos see, http://bclab.ucsd.edu/movementSpanMaterials). In total, 12 sequences were created with seven videos in each sequence with one video displaying one manual gesture. Each individual movement video lasted a total of 1.75 seconds (s), with an interstimulus interval (ISI) of 0.25s. As a result, each sequence lasted for a total of 14s. Two main experimental blocks were used in this experiment, containing 24 sequences each; one block with articulatory suppression (WS) and one block without suppression (NS). Within each of these blocks, there were three sound conditions; eight sequences were presented in silence (Sil), eight in the presence of steady-state irrelevant sound (SS), and eight in the presence of changing-state irrelevant sound (CS). Note, the same sequences were used in each block however, the order in which these sequences were presented was randomised by the software. Irrelevant sounds were edited onto the video sequences, with SS irrelevant sound consisting of repetitions of the syllable "*Ah*" and CS irrelevant sound consisting of the letters A through G with varying starting points. Irrelevant sounds were spoken at a rate of two per second. It should be highlighted that the irrelevant sounds adhered to those used within Jones et al. (1995). In the articulatory suppression block, participants were required to say aloud the word "*saxophone*" at a rate of once per second during presentation of the manual gestures. At the beginning of each block, a video of the movements that would be used in the experimental blocks was played through twice. Furthermore, a practice block containing three trials played in silence and containing no manual gestures used in the main experimental blocks, preceded each experimental block. For sequence reproduction, still images showing the end position of the movements were used, with care taken to ensure that no two images appearing on the same reproduction screen displayed similarities. The task was created using E-Prime 3 (Psychology Software Tools; Pittsburgh: PA).

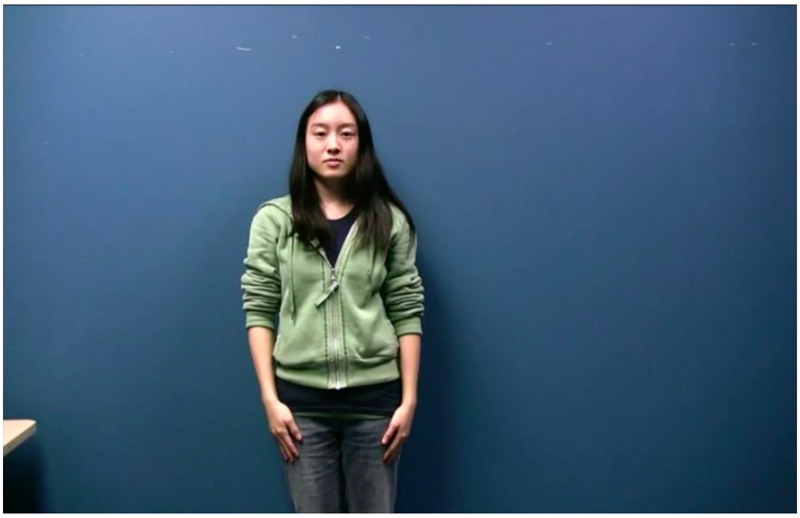

Figure 2.1: Image showing starting position of all manual gestures in Experiment 1.

Procedure

Participants were welcomed and asked to read through the information sheet (Appendix 3) had they not already done so. Once seated in front of the computer which ran the task, participants were able to read through the task instructions, with the researcher also providing verbal explanation. All participants were reminded of the requirement to wear headphones throughout the entire experimental procedure and prior to the articulatory suppression block, reminded of the requirement to articulate the word "*saxophone*" at a rate of once per second during presentation of the sequences; the researcher remained within earshot to ensure all participants complied with this instruction. Upon completion of the experiment, participants were debriefed via the use of a debrief sheet (Appendix 4) and also verbally by the experimenter. Participants were reminded that they were free to withdraw their data from the study up to the point of leaving the experimental session, after which data would be anonymised.

Figure 2.2: Image showing an example end position of a manual gesture in Experiment 1.

Statistical Analysis

A repeated measures ANOVA was carried out on mean performance scores to examine main effects of sound and suppression as well as interaction effects. Planned comparison paired samples t-tests were also carried out on mean performance scores to determine whether there was a significant difference in performance between steady- and changing-state irrelevant sound in each block of the experiment; reduced performance in changing-state trials compared to steady-state is indicative of the changing-state effect. A further repeated measures ANOVA was carried out on relative recency scores in order to investigate the effect of irrelevant sound and articulatory suppression on relative recency. This may provide insight into way in which manual gestures are encoded, allowing comparisons to be made between relative recency and effects of suppression and irrelevant sound between manual gestures and lipread and auditory stimuli. It should be noted that the relative recency measure was adopted over the more 'traditional' absolute recency as it provides a more robust measure of recency in the current experiment (as outlined by Maidment et al., 2013); overall performance within any given condition affects absolute recency and as there is an expectation that performance will differ across conditions, absolute recency is thus not the most appropriate measure to use. Finally, due to the repetition of sequences in Experiment 1, further repeated measures ANOVAs were carried out in order to determine if performance was affected by block and/or sequence order. The alpha level for all statistical analyses was set at .05. All analyses were carried out using Statistical Package for the Social Sciences (SPSS) 25 (IBM; United Kingdom) and Microsoft Excel (Microsoft; United States).

Chapter 3

Results

3.1 Serial Position Curves

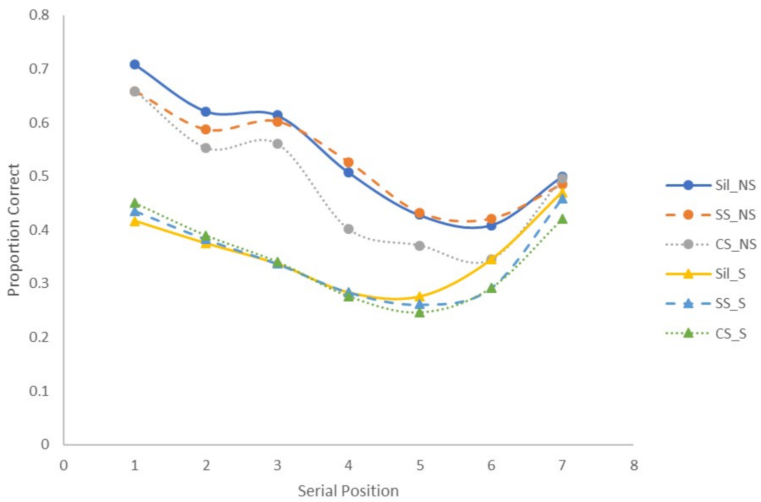

Figure 3.1: Serial position curves for all sound and suppression conditions in Experiment 1.

From Figure 3.1 it can be seen that the serial position curves obtained from Experiment 1 bear some resemblance to the characteristic bow-shaped curves found in previous verbal serial recall experiments. It is also apparent that serial recall performance is disrupted by irrelevant sound to some extent – note the slightly improved performance for steady-state, no suppression over silent, no suppression in the latter serial positions – with this disruption eliminated by articulatory suppression, and recall also noticeably enhanced for the final item in all conditions. It should also be highlighted that there is scalloping of the serial position curves within the no suppression condition after the second serial position. A 'typical' serial position curve displays a consistent reduction in performance from serial position one, with an increase in performance for the final item; however, the presence of scalloping within serial position curves is not unique to manual gestures (see, Section 4 for discussion).

3.2 Main Analysis

A 3 (sound: silent, steady-state, changing-state) × 2 (suppression: no suppression, with suppression) repeated measures ANOVA on mean performance scores for each participant revealed a significant main effect of suppression [$F(1,32) = 82.79, MSE = .02, p < .001, \eta^2 = .72$], a non-significant main effect of sound [$F(2,64) = 2.95, MSE = .07, p = .060, \eta^2 = .08$], and a non-significant interaction of sound and suppression [$F(2,64) = 1.29, MSE = .007, p = .283, \eta^2 = .04$] (see Appendix 5 for output).

3.3 Effect of Articulatory Suppression

Post-hoc paired samples t-tests were carried out on mean performance scores for each participant to determine the effect of suppression on each of the sound conditions. These revealed a significant difference between performance on silent, no suppression ($M = .54$, $SD = .19$) and silent, with suppression ($M = .36$, $SD = .14$) trials; $t(32) = 5.89, p < .001$; a significant difference between performance on steady-state, no suppression ($M = .55$, $SD = .18$) and steady-state, with suppression ($M = .35$, $SD = .13$) trials; $t(32) = 8.13, p < .001$; and a significant difference between performance on changing-state, no suppression ($M = .49$, $SD = .14$) and changing-state, with suppression ($M = .34$, $SD = .14$) trials; $t(32) = 7.20, p < .001$ (see Appendix 6 for output). Due to multiple comparisons being made, the Holm-Bonferroni correction (see, Gaetano, 2013; Holm, 1979) was used to protect against Type I error. All three post-hoc t-tests remained significant with a corrected p-value of .000 (see Appendix 7). These results clearly show that serial recall performance was significantly reduced by articulatory suppression.

3.4 Changing-state Effect

Planned comparison paired samples t-tests were carried out on mean performance scores for each participant to investigate whether the changing-state effect presented with manual gestures and whether this effect (if present) would be eliminated when articulatory suppression was employed. These revealed a significant difference between performance on steady- ($M = .55$, $SD = .18$) and changing-state ($M = .49$, $SD = .14$) trials in the no suppression condition; $t(32) = 2.40, p = .022$, with this significance eliminated upon the addition of articulatory suppression: steady-state, with suppression ($M = .35$, $SD = .13$); changing-state, with suppression ($M = .34$, $SD = .14$); $t(32) = .39, p = .701$ (see Appendix 8 for output). These results clearly show that the changing-state effect presents with manual gestures and is subsequently eliminated with the addition of articulatory suppression.

3.5 Relative Recency Analysis

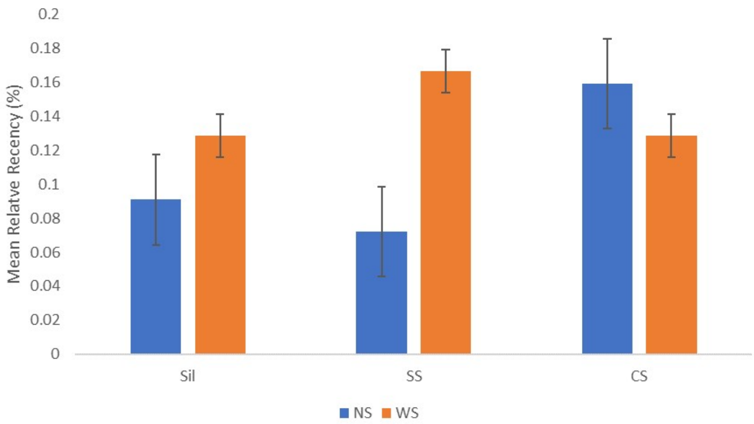

Figure 3.2: Graph showing relative recency for all experimental conditions in Experiment 1. Relative recency scores were calculated by taking performance on the final serial position (7), minus performance on the penultimate serial position (6) for each participant, and then finding the mean value. Error bars show the standard error of the mean.

A 3 (sound: silent, steady-state, changing-state) × 2 (suppression: no suppression, with suppression) repeated measures ANOVA on relative recency scores revealed non-significant main effects of sound [$F(2, 64) = .51, MSE = .04, p = .601, \eta^2 = .02$], suppression [$F(1, 32) = 2.16, MSE = .03, p = .151, \eta^2 = .06$], and a non-significant interaction of sound and suppression [$F(2, 64) = 1.59, MSE = .04, p = .213, \eta^2 = .05$] (see Appendix 9 for output). Despite the non-significant results, one interesting observation is that relative recency scores for both silent and steady-state trials improved when articulatory suppression was used compared to when it was not.

3.6 Block Analysis

Due to Experiment 1 utilising the same sequences in each block of the experiment, it was pertinent to determine whether learning effects arose as a result of the order in which participants undertook each block of the task. A 3 (sound: silent, steady-state, changing-state) × 2 (suppression: no suppression, with suppression) repeated measures ANOVA on mean performance scores for each participant, with block order (no suppression first, with suppression first) as a between subjects factor, revealed a significant main effect of suppression [$F(1, 31) = 84.72, MSE = .02, p =< .001, \eta^2 = .73$], a non-significant main effect of sound [$F(2, 62) = 2.86, MSE = .007, p < .065, \eta^2 = .09$], as well as a non-significant interaction of sound and suppression [$F(2, 62) = 1.24, MSE = .008, p = .296, \eta^2 = .04$], of sound and block order [$F(2, 62) = .05, MSE = .007, p = .952, \eta^2 = .002$], of suppression and block order [$F(1, 31) = 2.09, MSE = .02, p = .158, \eta^2 = .06$], and of sound, suppression, and block order [$F(2, 62) = .03, MSE = .008, p = .975, \eta^2 = .001$]. The between-participant main effect of block order was also non-significant [$F(1, 31) = .05, MSE = .098, p = .828, \eta^2 = .002$] (see

Appendix 10 for output).

3.7 Trial Analysis

In order to fully ensure that learning effects were not responsible for the results obtained in this experiment, performance over the duration of the experiment was assessed. A 3 (sound: silent, steady-state, changing-state) $\times$ 8 (trials: 1-8) repeated measures ANOVA, conducted using mean performance on each trial for each participant in the no suppression condition, revealed a significant main effect of sound [$F(2, 64) = 3.25, MSE = .07, p = .045, \eta^2 = .09$], a non-significant main effect of trial order [$F(4.86, 155.56) = 2.26, MSE = .095, p = .053, \eta^2 = .07$], and a non-significant interaction of sound and trial order [$F(14, 448) = 1.15, MSE = .064, p = .313, \eta^2 = .04$] (see Appendix 11 for output). Taken together, the results of the block and trial analyses show that learning effects were not responsible for increased performance over the course of the experiment.

Chapter 4

Discussion

Experiment 1 utilised meaningless manual gestures in an attempt to investigate how item order is maintained in serial recall of movements. One of the major issues with attempting to examine this lies in equating the serial recall task with others from the various domains of immediate memory. Avons (1998) argued that it is the characteristics of the task that determine the pattern of performance, suggesting that should serial recall tasks be equated, similar bow-shaped serial recall curves may be observed regardless of the nature of the input. Indeed, it appears that in Experiment 1 this bow-shaped pattern has been obtained, suggesting that the task was somewhat equated with others from previous research. From the curves (see, Figure 3.1) it can be seen that serial recall performance is reduced by irrelevant sound, with articulatory suppression negating this effect. Additionally, there is also a noticeable improvement in recall for the final item in each of the conditions, with these results bearing a close resemblance to previous research examining serial recall for lipread sequences.

As stated previously, it has been suggested that lipread sequences appear to behave in the same manner as auditorily presented sequences, with articulatory suppression eliminating the effect of irrelevant sound (Divin et al., 2001), and a modality effect for lipread sequences also being observed (Campbell & Dodd, 1980). As a result, it could be suggested that manual gestures are processed in the same manner however, this cannot be stated conclusively as recency effects have been observed with visual and spatial material (Avons, 1998; Farrand & Jones, 1996; Nairne & Dutta, 1992; Smyth et al., 2005; Smyth & Scholey, 1996; Tremblay, Parmentier, et al., 2006). There may be evidence from Experiment 1 however, when compared with results from Maidment et al. (2013), that may lead to the suggestion that gestures behave more similarly to auditory items than lipread. In Experiment 1 of Maidment et al. (2013), when compared with control, relative recency for auditory sequences is enhanced when articulatory suppression is utilised, with suppression reducing relative recency for lipread sequences. The same effect was observed here, with recency on silent trials also enhanced with the addition of articulatory suppression however, there is a noticeable difference with regard to the magnitude of the effect between studies.

Maidment et al. (2013) also found that the addition of changing-state irrelevant sound –

in the absence of articulatory suppression – resulted in almost identical (if not slightly improved) relative recency scores compared to control, with recency for lipread sequences reduced. In Experiment 1 of the current study, changing-state irrelevant sound caused an improvement in relative recency, with this improvement reduced by articulatory suppression. Thus, on the basis of relative recency scores, it appears that gestures behave in a somewhat similar manner to auditory items in STM. The authors also show that despite certain observed similarities between serial recall for auditory and lipread sequences, there is the suggestion that the mechanisms by which they manifest rely more on attentional and perceptual processes, both modality-specific and domain-general. Maidment et al. (2013) suggest that disruption of recency for a silently lipread sequence by an auditory suffix occurs as a result of attentional capture (see, Hughes, 2014), whereas disruption of recency for an auditory list by a silently lipread suffix occurs as a result of the lexical content of the suffix being misidentified by participants. Thus, there is a requirement for further research in order to fully investigate the way in which different forms of information are encoded and processed in STM.

From Figure 3.1, it can also be seen that there is some scalloping of the serial position curves within the no suppression condition; in each of the sound conditions, performance either improves or plateaus from serial position two, to serial position three. While a 'typical' serial position curve shows a somewhat uniform decrease in performance from serial positions one or two to serial positions five or six, with a increase in performance at serial positions six or seven, the curves obtained in the no suppression condition within Experiment 1 are not distinct to manual gestures. Madigan (1980) discusses the prevalence of this *Type II* curve – with the typical serial position curve being referred to as a *Type I* curve – making reference to a verbal serial recall study study conducted by Morton, Crowder, and Prussin (1971) which contained 32 instances of this form of serial position curve. It is believed that this shape of curve arises due to *chunking*.

The term chunking simply refers to the grouping together of individual pieces of information (see Cowan, Chen, & Rouder, 2004; Miller, 1956; Tulving & Patkau, 1962). One of the most common examples of chunking is observed with phone numbers; the digits are often grouped in a pattern, e.g., 012. . . 34. . . 56 to aid in memory, with the number being recalled in the same pattern. It is possible that chunking occurred in Experiment 1 in the no suppression condition, with participants grouping items 1-3 together, which results in a smaller serial position curve within the overall curve – performance is best at position one, decreases at position two, and gains some form of recency advantage at position three. It can also be seen from Figure 3.1 that there are some less prominent plateaus in performance at later positions in the changing-state no suppression condition.

The finding that articulatory suppression significantly disrupted serial recall performance for meaningless manual gestures conflicts with a central tenet of the WM model which states that disruption in a focal task is due to a secondary task drawing from the same WM resource (e.g., both tasks utilising the phonological loop). Results from Experiment 1 however, suggest that this is not the case, implying that disruption can occur regardless of whether the focal and secondary tasks draw from the same resource. The lack of an interaction between sound and suppression was surprising given that there is an expectation for articulatory suppression to eliminate the changing-state effect. Despite the main effect of sound being non-significant, the planned comparisons revealed the presence of a significant changing-state effect which was eliminated with articulatory suppression. This is at odds with the interference-by-content account of auditory distraction while offering support for the interference-by-process account.

Chapter 5

Experiment 2

5.1 Overview

Results from Experiment 1 show that serial recall for meaningless manual gestures displays similar characteristics to that of verbal serial recall. While this finding points towards a functional equivalence in the maintenance of order information across perceptual modalities, it is possible that participants were able to verbally recode the manual gestures. Even though the manual gestures in Experiment 1 were meaningless, participants may have been able to draw some similarities between these and known gestures, thus adding a verbal label and subvocally rehearsing this label. If this was the case, it could be argued that the similarities observed between the results obtained from Experiment 1 and those from verbal serial recall are due to the use of verbal performance strategies. As such, Experiment 2 aims to make the potential use of verbal recoding more difficult by using non-iconic manual gestures as the stimuli. An iconic gesture is one which contains some semantic content related to the meaning of accompanying speech. In contrast, a non-iconic gesture contains no semantic content related to the meaning of accompanying speech, thus, making it extremely difficult to verbally label (see, McNeill, 1985; Rudner, 2015). As such, this should provide a better insight into the idea of a functional equivalence in STM as it will reduce the potential for verbal recoding.

5.2 Method

Participants, Design, and Ethics

Eighteen (18) participants (female; $N = 11$; age; $M = 28.72$; $SD = 11.90$; Appendix 12) consented (see, Appendix 2) to take part in this study. All participants had normal or corrected-to-normal visual acuity and hearing and participants were not fluent in either British or Swedish sign language. Participants were awarded a small honorarium for taking part. A within-participant design was used, with all participants completing all aspects of the task. Ethical approval was obtained from the University of Central Lancashire Ethics Committee.

Serial Recall Task

A simple serial recall task – similar to that used in Experiment 1 – was utilised in this experiment however, sequences of videos depicting *non-iconic* (see, Rudner, 2015) manual gestures were used in place of meaningless manual gestures and the total number of trials were increased. In total, 30 unique sequences were created, with seven videos in each sequence. Each individual movement video lasted a total of 1.75s, with an ISI of 0.25s. As a result, each sequence lasted for a total of 14s. The same experimental blocks were used in this experiment (WS, NS), with the same sound conditions (Sil, $N = 10$; SS, $N = 10$; CS, $N = 10$) in each block. The same irrelevant sounds used in Experiment 1 (repetition of the syllable *"Ah"* or the letters A through G) were again edited onto each video sequence. In order to control for potential learning effects, the sound condition sequences were presented under differed between blocks; Sil trials within the NS block became CS trials within the WS block, SS trials within the NS block became Sil trials within the WS block, and CS trials within the NS block became SS trials in the WS block. Additionally, no gestures were repeated in the same serial position within each block and no gestures were repeated within each sound condition. The same articulatory suppression used in Experiment 1 (articulation of the word *"saxophone"*) was again used in this experiment. Practice blocks containing three trials played in silence and containing no gestures used in the main experimental blocks, preceded each experimental block. For sequence reproduction, still images showing the end position of the movements were used, with care taken to ensure that no two images appearing on the same reproduction screen displayed similarities. The task was created using E-Prime 3 (Psychology Software Tools; Pittsburgh: PA).

Figure 5.1: Image showing starting position of all non-iconic gestures in Experiment 2.

Procedure

Participants were welcomed and asked to read through the information sheet (see, Appendix 13) had they not already done so. Once seated in front of the computer that ran the task, participants were able to read through the task instructions, with the researcher providing verbal explanation. All participants were reminded of the requirement to wear headphones throughout the entire experimental procedure and prior to the articulatory suppression block, reminded of the requirement to articulate the word *"saxophone"* at a rate of once per second during presentation of the sequences; the researcher remained within earshot to ensure all participants complied with this instruction. Upon completion of the experiment, participants were debriefed through the use of a debrief sheet (see, Appendix 14) and also verbally by the experimenter. Participants were reminded that they were free to withdraw their data from the study up to the point of leaving the experimental session, after which data would be anonymised.

Figure 5.2: Image showing an example end position of a non-iconic gesture in Experiment 2.

Statistical Analysis

A repeated measures ANOVA carried out on mean performance scores to examine main effects of articulatory suppression and irrelevant sound as well as interaction effects. The same planned comparison paired samples t-tests used in Experiment 1 were also carried out on mean performance scores for steady- and changing-state irrelevant sound conditions in each experimental block to determine if the changing-state effect presented. The same relative recency analysis used in Experiment 1 was also employed here. The alpha level for all statistical tests was set a .05. All statistical analysis was carried out using SPSS 25 (IBM; United Kingdom) and Microsoft Excel (Microsoft; United States).

Chapter 6

Results

6.1 Serial Position Curves

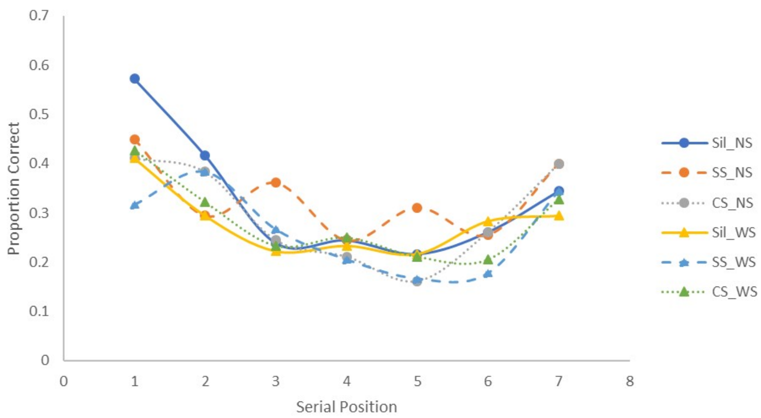

Figure 6.1: Serial position curves for all sound and suppression conditions in Experiment 2.

From Figure 6.1, it can be seen that performance is noticeably reduced compared to performance in Experiment 1 (see, Figure 3.1). In both silent conditions, it appears that the curves are somewhat similar to the serial position curves observed in other serial recall studies however, there is a great deal of variability in the serial position curves for all other conditions. Additionally, there appears to be significantly more scalloping within the curves, suggesting that chunking was employed to a greater extent than in Experiment 1. This may be due to the difference in stimuli used; the non-iconic manual gestures used in Experiment 2 may have indeed made verbal recoding more difficult for participants thus, there may have been a reliance on chunking to maintain item order.

6.2 Main Analysis

A 3 (sound: silent, steady-state, changing-state) × 2 (suppression: no suppression, with suppression) repeated measures ANOVA on mean performance scores for each participant revealed a significant main effect of suppression [$F(1, 17) = 8.51, MSE = .006, p = .010, \eta^2 = .33$], a non-significant main effect of sound [$F(2,34) = .61, MSE = .003, p = .551, \eta^2 = .03$], and a non-significant interaction effect of sound and suppression [$F(2,34) = 1.23, MSE = .005, p = .306, \eta^2 = .07$] (see Appendix 15 for output).

6.3 Effect of Articulatory Suppression

Post-hoc paired samples t-tests were carried out on mean performance scores for each participant to determine the effect of suppression on each sound condition. Again, due to multiple comparisons being made, the Holm-Bonferroni correction (Gaetano, 2013; Holm, 1979) was used to protect against Type I error. Results revealed a non-significant difference between silent trials ($p = .09$), steady-state trials ($p = .07$), and changing-state trials ($p = .56$; see Appendix 16 for output) across suppression conditions, with these results suggesting a floor effect was reached with regard to the changing-state irrelevant sound condition and articulatory suppression. It should be pointed out that, prior to correction, all p-values were significant.

6.4 Changing-state Effect

Planned comparison paired samples t-tests were carried out on mean performance scores for each participant to investigate whether the changing-state effect presented with non-iconic manual gestures and whether articulatory suppression would eliminate this effect if present. These tests revealed a non-significant difference between steady- and changing-state trials in the no suppression condition ($p = .17$) and a non-significant difference between steady- and changing-state trials in the suppression condition ($p = .48$; see Appendix 17 for output).

6.5 Relative Recency Analysis

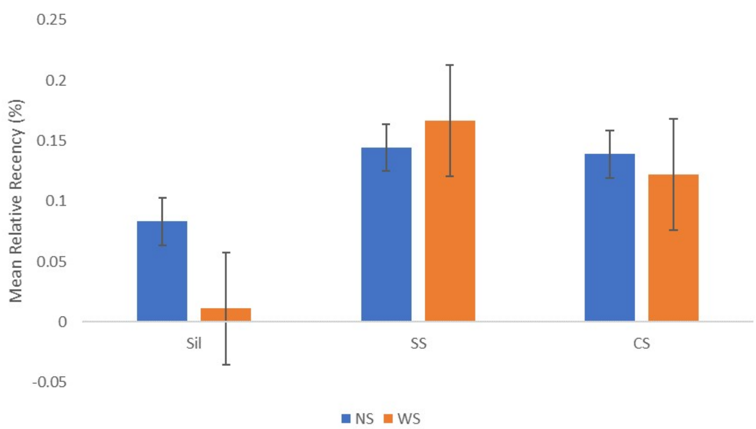

Figure 6.2: Graph showing relative recency for all experimental conditions in Experiment 2.

Relative recency was again used in an attempt to investigate the way in which manual gestures are processed in STM. A 3 (sound: silent, steady-state, changing-state) × 2 (suppression: no suppression, with suppression) repeated measures ANOVA on relative recency scores revealed a significant main effect of sound [$F(2, 34) = 4.54, MSE = .03, p = .018, \eta^2 = .21$], a non-significant main effect of suppression [$F(1, 17) = .57, MSE = .02, p = .462, \eta^2 = .03$], and a non-significant interaction effect of sound and suppression [$F(2, 34) = .54, MSE = .04, p = .590, \eta^2 = .03$] (see Appendix 18 for output). Post-hoc paired samples t-tests revealed a significant difference between silent, with suppression ($M = .01$, $SD = .15$) and steady-state, with suppression ($M = .17$, $SD = .20$) relative recency scores; $t(17) = 3.15$, $p = .036$. All other results were non-significant and again, the Holm-Bonferroni correction was used to protect against Type I error (see Table 6.1; see also, Appendix 19 for output). While relative recency was improved on steady-state with suppression trials compared to without suppression, suppression reduced relative recency for silent trials, contrasting results observed in Experiment 1.

Table 6.1: Table showing means, standard deviations, significance values, and corrected significance values for all non-significant relative recency post-hoc tests

Pair	Sil-NS × SS-NS	Sil-NS × CS-NS	SS-NS × CS-NS	Sil-WS × SS-WS	Sil-WS × CS-WS	SS-WS × CS-WS
M	.083 × .144	.083 × .139	.144 × .139	.011 × .167	.011 × .122	.167 × .122
SD	.203 × .146	.203 × .191	.146 × .191	.149 × .203	.149 × .152	.203 × .152
p	.373	.410	.926	.006	.030	.502
p (corrected)	1.00	1.00	1.00	.036	.150	1.00

Chapter 7

Discussion

Experiment 2 employed the use of non-iconic manual gestures in an attempt to prevent participants from utilising verbal recoding as a performance strategy. As stated previously, non-iconic gestures are difficult to verbally label due to their lack of semantic content and as such, verbal recoding becomes a less effective strategy for maintaining item order. From Figure 6.1, it can be seen that the use of non-iconic gestures may indeed have reduced participants ability to verbally recode the movements as overall performance is reduced when compared with performance in Experiment 1. Support for this view may be provided by the increased prevalence of scalloping observed in the serial position curves in Experiment 2. This may suggest that participants relied on chunking as a performance strategy, potentially due to the ineffectiveness of verbal recoding. However, it is also possible that overall performance may have been reduced as a result of the complexity of the task (see later in this section). While there appears to be considerably more variability in the serial position curves in Experiment 2, it should be noted that both silent conditions displayed a somewhat similar bow-shaped curve found in Experiment 1 and previous research into serial recall for other forms of immediate memory.

With regard to the relative recency results observed in Experiment 2, while there was a significant main effect of sound, this should be interpreted with a high degree of caution; no effect was found in Experiment 1 which consisted of a much larger sample size and from previous research, it is evident that sample size may dictate the presence or absence of a significant result (see e.g., Jones et al., 1995; Kvetnaya, 2018). However, there are some similarities to be highlighted between the experiments. Again, the addition of articulatory suppression caused relative recency performance to improve with steady-state irrelevant sound and reduce with changing-state irrelevant sound – on silent trials, performance was reduced in contrast to the improvement observed in Experiment 1. This pattern of results may prove a fruitful starting point for further investigation into the manner in which manual gestures are processed however, to reiterate, caution should be taken when interpreting the relative recency results obtained in Experiment 2 given the small sample size.

Interestingly, while the curves for no suppression and suppression blocks in Figure 6.1 lack the same distinct separation seen in Experiment 1 (see Figure 3.1), a significant main effect of articulatory suppression was found, indicating disruption of serial recall performance. While post-hoc tests did reveal significant differences between silent and steady-state and silent and changing-state trials, these became non-significant upon correction. It is possible that with a larger sample size, the significant differences found during initial analyses may survive correction, as observed in Experiment 1. Despite this, the mere suggestion that articulatory suppression can disrupt serial recall of manual gestures shown in this study goes against the view of the WM model in that reduced performance on a focal task is as a result of a secondary task or distractor utilising the same WM resources.

While a significant changing-state effect was found in Experiment 1, no such effect presented in Experiment 2. This may be due to some of the limitations of the experiment, two of which warrant further discussion in this section. First, the sample size is considerably lower than that of Experiment 1. As can be seen from (Kvetnaya, 2018), sample size can have a considerable effect on the outcome of a study; while (Kvetnaya, 2018) found non-significant results compared to the significant results found in (Jones et al., 1995), it is still possible that with a larger sample size, significant results may have been observed with regard to the changing-state effect, particularly given the results of Experiment 1 however, it should be reiterated that the results in Experiment 1 may have been obtained due to the use of verbal recoding.

Secondly, the demands of the task may also have contributed to the non-significant changing-state effect. While task difficulty and participant focus were not recorded during either Experiment 1 or 2, upon completion of Experiment 2, a number of participants reported that the task was extremely difficult, with some reporting that they used guessing in order to reconstruct some of the sequences[1]. Therefore, it could be suggested that the difficulty of the task may have caused participants to lose focus and employ guessing in order to complete the task. Clearly, this would not facilitate the manifestation of the changing-state effect however, these are purely subjective reports and future research should include more objective measures of task difficulty and participant focus.

[1]When data from participants with an average performance of .3 or higher across steady- and changing-state trials, both with and without articulatory suppression were analysed, the changing-state effect presented which was subsequently eliminated by articulatory suppression. However, the conclusions that can be drawn from this, and indeed, Experiment 2 in general, are limited due to the small sample size

Chapter 8

General Discussion

8.1 Overview

The present study aimed to investigate how order information is maintained for sequences of manual gestures. Previous research on verbal, spatial, and visual domains alludes to an amodal mechanism for the maintenance of order information in serial recall (e.g., Jones et al., 1995; Smyth et al., 2005) however, there is minimal research relating to how order is maintained for sequences of manual gestures, and indeed, movements in general. While results of the present study are somewhat mixed, there are some of note which should be useful to the ongoing debate regarding the notion of functional equivalence, as well as in relation to models of serial STM and auditory distraction. It is important to highlight that while there are some limitations with regard to the tasks used in the current study, they appear to have been equated with other serial recall tasks to some extent. Avons (1998) suggested that should serial recall tasks be equated with regard to task composition and demands, similar bow-shaped serial position curves should result. Indeed, this appears to be the case in the current study (to a greater extent in Experiment 1), with both Type I and Type II curves being observed. In terms of the primacy model (Page & Norris, 1998) – which models the function of the phonological loop – the majority of serial position curves from the current study follow the model in that recall at serial position one is maximal (however, see Figure 3.1, steady-state, with suppression) and that performance decreases as the sequence progresses, with some exceptions in the current study. Thus, it should be stated that the results should be interpreted with some degree of caution.

8.2 Processing of Manual Gestures in Short-term Memory

As stated previously, there is a distinct lack of research into how manual gestures are processed in STM. Despite some research suggesting that an aspect of the visuospatial sketchpad plays a role in this (see e.g., Baddeley, 1983, 2007; Smyth et al., 1988; Smyth & Pendleton, 1989), with movements stored in a kinaesthetic code, it has not been fully elucidated as to whether this kinaesthetic code is distinct from, or draws upon visual and spatial processing. Indeed, there is also the distinct possibility that processing of movements in STM draws upon verbal processes (i.e., verbal recoding and subvocal rehearsal), with reduced performance as a result of an inability to verbally recode and therefore rehearse movements. In relation to previous research examining serial recall for manual gestures, Wilson and Fox (2007) suggested that an 'articulatory' loop for movements, facilitated by sensory and motoric processes, could be responsible for the maintenance of order information. The results of the current study support this notion in theory however, it remains to be determined whether the mechanism by which order information is maintained for manual gestures is a distinct entity or an amodal mechanism, responsible for order maintenance across all STM domains. A direction for future research could be to utilise various suppression tasks (e.g., articulatory suppression, tapping) in order to determine which causes most disruption to serial recall of manual gestures.

The addition of relative recency analyses was in service to a secondary aim of the study to investigate the way in which manual gestures are processed in STM. While the results should indeed be interpreted with a degree of caution, there are some interesting patterns. The addition of articulatory suppression was able to – in both experiments – increase relative recency scores with changing-state irrelevant sound and reduce relative recency scores with changing-state irrelevant sound. While some of the scores observed follow along with previous research examining relative recency for lipread and auditory material (see, Maidment et al., 2013), there is a need for further research with the main goal of comparing and contrasting the encoding and processing of various forms of information in STM with, based on the results of the current study, a particular focus on the impact of articulatory suppression and irrelevant sound.

8.3 The Effect of Irrelevant Sound

The stimuli used as the TBR material in both experiments of the current study was non-phonological and as such – on the WM model – disruption by means of irrelevant sound interfering with TBR items should not be possible; however, results from the current study go against this central tenet of the WM model (see e.g., Postle, 2006). Indeed, it could be suggested that participants utilised verbal recoding that allowed some verbal representation of the movement to enter the phonological store however, to assume that participants had the ability to verbally recode and rehearse each meaningless or non-iconic gesture given each movement lasted a total of 1.25s, with an ISI of 0.75s, could be considered somewhat implausible. This is particularly true when considering the non-iconic nature of the gestures used in Experiment 2 however, comparison of the results from each experiment may lead to this suggestion. Despite this potential conflict, as the stimuli used were non-phonological and, in theory, did not gain access to the phonological store, disruption of serial recall performance by irrelevant sound provides support for the interference-by-process account of auditory distraction over the interference-by-content account.

The interference-by content account of auditory distraction states that disruption of serial recall performance is mediated by the similarity of the TBR and TBI items (Cowan, 1999; Oberauer & Lange, 2008; Salamé & Baddeley, 1982). As stated previously, the stimuli used in both experiments of the current study were distinctly dissimilar, with short videos depicting manual gestures used in the TBR sequences and speech sounds used in the TBI sequences. Therefore, it cannot be suggested that the similarity between the TBR and TBI items was the cause of any disruption. Rather, the results from the current study, particularly those from Experiment 1, provide support for the interference-by-process account (see e.g., Hughes et al., 2013; Hughes et al., 2005, 2007), which states that the process of maintaining item order for both the TBR and TBI stimuli, interfere with each other, resulting in reduced serial recall performance. Thus, the result obtained from the current study, suggest that, in its current state, the WM model is not best suited to account for the disruption of serial recall for manual gestures by irrelevant sound; rather, the perceptual-gestural account (see, Hughes et al., 2016; Hughes & Marsh, 2017; Hughes et al., 2009; Jones et al., 2006, 2007; Jones et al., 2004; Macken & Jones, 2003) better accounts for the disruption observed.

The perceptual-gestural account posits that general-purpose perceptual input and motor output processes are co-opted in order to meet the demands of a task, with subvocal rehearsal binding the items within a sequence into a single motor object in verbal serial recall, thus constraining item order (see, Hughes et al., 2016, see also, Section 1.3). As stated previously, it cannot be assumed that participants verbally recoded the TBR items, therefore it cannot be assumed that rehearsal was utilised in order to maintain the order of the TBR sequences however, the perceptual-gestural account has been extended to include oculomotor processes (see, Guérard & Tremblay, 2011) therefore, there is the possibility that it could be extended to manual gestures. Given that the interference-by-process account suggests an amodal representation of order information across memory domains, it is expected that serial recall performance for manual gestures would be impaired, as it was in Experiment 1, with the potential that the same, more substantial disruptions would have been observed in Experiment 2 with a larger sample size. This falls in line with the disruption of serial recall for spatial material by changing-state irrelevant sound (see e.g., Jones et al., 1995) however, this remains to be elucidated further given the results of (Kvetnaya, 2018) and our lab (Marsh et al., unpublished data). It may also be possible that the primacy model (Page & Norris, 1998) could account for the changing-state effect observed in Experiment 1 however, this would only be the case if verbal recoding was utilised by participants.

While there is little known regarding how order information for sequences of manual gestures is maintained in STM, there has been the suggestion that the manual-motoric system is recruited in order to better retain sequences of movements. Evidence in support of this view can be found in studies that have utilised electromyography (EMG). For example, Morsella and Krauss (2005) requested that their participants retrieve a word from a presented definition. The results showed increased electromyographic activity when the words were concrete (e.g., castanets) compared with abstract words (e.g., paradox). As such, should the manual-motoric system be co-opted in order to retain the order of sequences of movements in STM, the disruption of serial recall as a result of irrelevant sound could be better accounted for by not only the perceptual-gestural account, but also the interference-by-process account of auditory distraction as this account does not place focus on the similarity of the TBR and TBI items, but rather the simultaneous process of maintaining item order.

8.4 The Effect of Articulatory Suppression

The perceptual-gestural account may also be better suited to account for the disruption observed as a result of articulatory suppression. On the WM model, articulatory suppression is believed to impede the revivification of decaying memory traces within the phonological store, as well as prevent the conversion of of visual-verbal material to phonological from (see, Baddeley, 2003; Baddeley et al., 1975, see also, Section 1.5). As the material within the TBR sequences in the present study are neither phonological or verbal in nature, and it cannot be assumed that participants were able to effectively utilise verbal recoding, it thus, cannot be inferred that articulatory suppression resulted in disruption of performance by preventing revivification or conversion of the TBR items. Additionally, the results from the current study are at odds with a central view of the WM model which states that disruption on a focal task occurs as a result of a secondary task or distractor drawing from the same WM resource (e.g., both focal and secondary tasks utilising the phonological loop). As stated, the TBR material used in both experiments was non-phonological meaning it cannot be robustly stated that disruption by articulatory suppression was caused by overuse of the same WM resource. Since it remains to be determined whether the processing of manual gestures relies more on verbal or visual-spatial processes, it would be pertinent to examine if the use of tapping as a secondary task disrupts serial recall of manual gestures to a greater extent than articulatory suppression.

As previously discussed, there is a suggestion that the manual-motoric system is adopted in order to maintain sequences of manual gestures in STM. If this is indeed the case, disruption of serial recall as a result of articulatory suppression may be caused by a high demand being placed on the motor system. As the perceptual-gestural account states, items within a sequence are bound in a single motor object, meaning both TBR and TBI sequences would be bound in the same manner. Paired with the addition of articulatory suppression which is known to utilise vocal-motor processes, it may be suggested that this places a high demand on the motor system, with this increased demand leading to disruption of performance. Indeed, it seems reasonable to invoke this limitation of the motor system as it appears somewhat analogous to the view of the WM model wherein disruption on a task is as a result of primary and secondary tasks drawing from the same WM resource however, in the case of the former, there is no need to invoke conceptual storage mechanisms.

8.5 Evidence for an Amodal Seriation Mechanism

The results from the current study offer some support for the notion of an amodal mechanism for the maintenance of order information in STM. As the stimuli in the TBR sequences are non-phonological and it cannot be assumed that participants utilised verbal recoding in order to remember the order of items, it cannot therefore be stated that subvocal rehearsal was used to maintain the order of the items within the TBR sequences. This leads to the suggestion that order information is maintained by some other mechanism that can be disrupted by irrelevant sound and articulatory suppression. There are also a number of similarities between the results of the current study and previous research in the various domains of immediate memory which provide further support for this view.

Experiment 1 of Jones et al. (1995) found that serial recall for spatial items resulted in both primacy and recency effects with a number of other studies (Avons, 2007; Farrand et al., 2001; Guérard & Tremblay, 2008; Tremblay, Parmentier, et al., 2006) providing evidence in support of this finding. That the serial position curves from both experiments of the current study display similar characteristics to that of Jones et al. (1995) and previous research utilising verbal serial recall, offers support for the suggestion of Jones and colleagues in that this provides some degree of support for a functional equivalence between not only verbal and spatial material, but now also manual-gestural material. The results of Experiment 1 in the current study are similar to those obtained in Experiment 4 of Jones et al. (1995) in that both steady- and changing-state irrelevant sound was able to disrupt serial recall performance, with changing-state irrelevant sound being significantly more disruptive. However, it should be noted that Kvetnaya (2018) failed to find an effect of sound type, which is also consistent with the results obtained in the current study, even though significant differences were found with planned comparisons in relation to the changing-state effect.

In relation to previous visual STM research, the effect of articulatory suppression observed in the present study is similar to that observed in Experiment 2 of Smyth et al. (2005). It was shown that both articulatory suppression and spatial tapping disrupted serial recall for faces however, articulatory suppression was more disruptive. Taken together with the result of the current study, this provides evidence in support of either a domain-general mechanism for the maintenance of item order, or at least, a domain-specific mechanism which results in similar effects due to the similarity of their action, a view adopted by Smyth et al. (2005). This is based on the fact that performance on both visual and manual-gestural serial recall tasks have been shown to be disrupted by articulatory suppression, a distinctly phonological task.

While it cannot be conclusively stated that an amodal mechanism is responsible for the maintenance of item order, it could be suggested that the results show maintenance of order information for manual gestures is maintained by the same mechanism responsible for the maintenance of order information for visual items given the similarities between the results of the current study and the results observed in Smyth et al. (2005). Further research is needed to determine whether this mechanism is responsible for the maintenance of order information for all forms of stimuli, with further equating of the serial recall task for manual gestures key to determining whether this is the case.

8.6 Limitations and Considerations

Clearly, there are a number of limitations with the current study, not least the sample size of each experiment, particularly Experiment 2. Another noteworthy limitation was the reuse of sequences across blocks in each of the experiments. As Avons (1998) argued, should serial recall tasks be equated across memory domains, similar results may be observed. While the tasks utilised in Experiments 1 and 2 were equated in terms of overall structure, the sequences themselves contained a rather large number of *distinct* stimuli compared to, for example, the closed sets used in verbal serial recall thus, making it illogical to assume that similar serial position effects would arise. Additionally, the stimuli used were not from a learned set, as is the case with most verbal serial recall studies, hence the reuse of sequences across blocks in Experiment 1. Furthermore, while the movements used in Experiment 1 were played twice at the beginning of each block, it cannot be assumed that participants had sufficient time to learn these.

It is also worth stating that the stimuli used within Experiment 2 may have impacted upon performance. In Experiment 1, the stimuli depicted gross movements of the hands and/or arms, whereas in Experiment 2, there were a number of smaller hand movements within the overall movement which could lead to the suggestion that participants had to maintain a sequence of movements for *each item* within the TBR sequence. Furthermore, the use of still images on the order reconstruction screen was a significant limitation of each experiment. The task required participants to remember the order of sequences of manual gestures and had the order reconstruction screen shown videos or graphic interchange formats (GIFs), this may have resulted in improved performance. Unfortunately, this was out of the control of the researcher as the software was unable to deal with such heavy demand given that there was a minimum of 84 videos in each block of the experiments. While this can be seen as a limitation, it may also highlight a potential direction for future research. Reproduction of the sequences in these experiments was achieved through the use of still images which may suggest that participants were utilising *visual* STM rather than some form of kinaesthetic STM. Subsequent research may benefit from examining the possibility that memory for sequences of movements does not rely on a currently undefined kinaesthetic store, but rather from visual and spatial mechanisms that are already known to give rise to similar results.

Another limitation in the current study was in the attempt to prevent participants from utilising verbal recoding and subvocal rehearsal. While the re-enactment of movements may have reduced participants desire to verbally recode the manual gestures, enactment of a movement (or action phrase, e.g., 'waving') has been shown to improve item-specific processing however, it does not improve relational processing (i.e., processing the items based on relations with one another, e.g., the order items were presented; Engelkamp and Dehn, 2000). However, an interesting direction for future research would be to utilise mental re-enactment of movements during manual-gestural serial recall as this would act as an analogue of subvocal rehearsal, allowing for a more direct comparison of the effects of irrelevant sound and articulatory (and spatial) suppression. It would also be beneficial to directly compare performance on manual-gestural serial recall with that of verbal, spatial, and visual material, utilising as close to identical methodologies as possible.

As such, there are a number of considerations for future research. First and foremost, the serial recall task used should be equated to a greater extent in order to provide more validity and reliability. For example, a small, closed group of manual gestures could be provided to participants prior to the experimental procedure. Participants could then be given a short period of time to learn these manual gestures via re-enactment. This may encourage participants to use some form of mental re-enactment of the gestures rather than a reliance on verbal recoding however, the learning phase should be done in the presence of the researcher to ensure that participants do not add verbal labels to each of the stimuli. The task itself could then include sequences of the learned gestures, or smaller, constituent parts of the gestures in order to further reduce the potential for verbal recoding. The order reproduction screen should also replay the gestures contained within the TBR sequences rather than use still images. While this is one potential method for future research, it would be pertinent to examine all possible methods for examining serial recall of manual gestures in order to optimally equate this task with others from previous research in other domains of immediate memory.

8.7 Conclusion

The findings from the current study, while inconclusive, provide some evidence for a functional equivalence across domains of immediate memory, as well as the suggestion that manual gestures are encoded in a manner similar to that of auditory material, i.e., heard and not seen. Clearly, further research needs to be carried out in order to fully determine if a domain-general or domain-specific mechanism is responsible for the maintenance of item order however, the results obtained in this study show distinct similarities to serial recall for other domains of immediate memory thus, pointing towards an amodal mechanism. Additionally, the results of this study suggest that the perceptual-gestural account, rather than the WM model, is currently in a better position to account for the effects observed; however, the requirements for further research leaves not only the notion of a functional equivalence across domains of STM, but also the model which can best account for these effects, yet to be fully elucidated.

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Appendix A

Appendices

Appendix 1

Means

Case Processing Summary

	Cases					
	Included		Excluded		Total	
	N	Percent	N	Percent	N	Percent
Age * Gender	33	100.0%	0	0.0%	33	100.0%

Report

Age

Gender	Mean	N	Std. Deviation
Female	23.1304	23	4.70304
Male	21.5000	10	2.41523
Total	22.6364	33	4.17446

Appendix 2

WARNING

By pressing "Enter" on this screen you are providing consent to participate in this study.

If you do not wish to participate in the study at this point, please inform the experimenter.

Please note that you are free to withdraw from the study at any point during the experiment, even upon completion.

You will be reminded of your right to withdraw prior to leaving the session today.

If you consent to taking part in this study, please press "Enter" to begin.

Appendix 3

Short-Term Memory for Movements: Information Sheet

Overview of Experiment

The main aim of this study is to examine the ability to remember a sequence of manual-gestures (movements). Upon providing consent, you will be asked to complete a computer-based task which involves sequences (made up of short videos) depicting hand and arm movements. Some of the sequences will be silent, while others will contain irrelevant background sound (played through headphones) which you will be instructed to ignore and will not be tested on. In one of the blocks, you will also be required to say the word "*saxophone*" aloud at a rate of once per second. The goal of the task is to reproduce the order in which the movements appeared. The study should take no longer than one hour, and participation is entirely voluntary. As this study contains visual and auditory elements, you should have normal or corrected-to-normal vision and hearing.

Compensation

For taking part in this study, you will be awarded four SONA points (for School of Psychology students) or a £5 Amazon voucher.

Should you wish to take part in the study or require further information, please contact the researcher;

Researcher:	Director of Studies:	First Supervisor:	Second Supervisor:
Stuart Moore	Dr John Marsh	Professor Linden Ball	Dr Reyhan Furman
SBMoore@uclan.ac.uk	JEMarsh@uclan.ac.uk	LBall@uclan.ac.uk	RFurman@uclan.ac.uk

Appendix 4

<u>Short-Term Memory for Movements: Debrief Sheet</u>

First, I would like to take this opportunity to thank you for taking part in my study and I will now explain the purpose of the study.

The data collected today will be used to examine serial recall performance for manual-gestures (movements). As you know, serial recall tasks involve reproducing a sequence of items in the order presented and while there is a significant amount of research relating to serial recall performance for verbal (e.g., letters, digits, words) and spatial (e.g., locations) items, there is a lack of research relating to performance for movements. It has been suggested that the ability to maintain items in the presented order is facilitated by the same mechanism regardless of the nature of the information (e.g., verbal, spatial, manual-gestural; Jones, Farrand, Stuart, & Morris, 1995). Therefore, serial recall performance for each of these types of information should exhibit the same pattern however, there has been no research regarding performance for manual-gestures. The data collected in this study will allow for examination of this hypothesis.

This can be further tested with the addition of articulatory suppression and irrelevant sound. Articulatory suppression prevents rehearsal of verbal information, thus resulting in reduced serial recall performance. While this is used mostly in verbal serial recall studies, it was employed in this study to prevent verbal recoding of the movements (e.g., giving each movement a name) and it has also been shown to disrupt performance in spatial serial recall (Jones et al. 1995). Furthermore, the use of irrelevant sound will allow testing of the changing-state hypothesis (Jones & Macken, 1993, 1995, Jones, Madden, & Miles, 1992; Macken & Jones, 1995), where irrelevant sound that changes from item to item (i.e., a, b, c, d…) disrupts serial recall performance to a greater extent than irrelevant sound that stays the same (i.e., a, a, a, a). This is due to both the serial recall task and the changing-state irrelevant sound containing information relating to the order of the items (known as interference by process; e.g., Beaman & Jones, 1997).

I would like to remind you that this is the final opportunity to withdraw from the study as your data will be anonymised when you leave the session. Should you have any follow up questions or queries, please contact the researcher or alternatively, the supervisory team.

Researcher: Stuart Moore	Director of Studies:	First Supervisor:	Second Supervisor:
	Dr John Marsh	Professor Linden Ball	Dr Reyhan Furman
SBMoore@uclan.ac.uk	JEMarsh@uclan.ac.uk	LBall@uclan.ac.uk	RFurman@uclan.ac.uk

If you have any concerns about the research that you wish to raise with somebody independent of the research team, contact the University Officer for Ethics (OfficerForEthics@uclan.ac.uk).

Appendix 5

General Linear Model

Within-Subjects Factors

Measure: MEASURE_1

Sound	Suppression	Dependent Variable
1	1	SiL_NS
	2	SiL_S
2	1	SS_NS
	2	SS_S
3	1	CS_NS
	2	CS_S

Descriptive Statistics

	Mean	Std. Deviation	N
SiL_NS	.5411	.18790	33
SiL_S	.3550	.14388	33
SS_NS	.5487	.17560	33
SS_S	.3469	.13341	33
CS_NS	.4946	.14014	33
CS_S	.3398	.13986	33

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df
Sound	Pillai's Trace	.137	2.465[b]	2.000	31.000
	Wilks' Lambda	.863	2.465[b]	2.000	31.000
	Hotelling's Trace	.159	2.465[b]	2.000	31.000
	Roy's Largest Root	.159	2.465[b]	2.000	31.000
Suppression	Pillai's Trace	.721	82.785[b]	1.000	32.000
	Wilks' Lambda	.279	82.785[b]	1.000	32.000
	Hotelling's Trace	2.587	82.785[b]	1.000	32.000
	Roy's Largest Root	2.587	82.785[b]	1.000	32.000
Sound * Suppression	Pillai's Trace	.078	1.307[b]	2.000	31.000
	Wilks' Lambda	.922	1.307[b]	2.000	31.000
	Hotelling's Trace	.084	1.307[b]	2.000	31.000
	Roy's Largest Root	.084	1.307[b]	2.000	31.000

Multivariate Tests[a]

Effect		Sig.	Partial Eta Squared
Sound	Pillai's Trace	.101	.137
	Wilks' Lambda	.101	.137
	Hotelling's Trace	.101	.137
	Roy's Largest Root	.101	.137
Suppression	Pillai's Trace	.000	.721
	Wilks' Lambda	.000	.721
	Hotelling's Trace	.000	.721
	Roy's Largest Root	.000	.721
Sound * Suppression	Pillai's Trace	.285	.078
	Wilks' Lambda	.285	.078
	Hotelling's Trace	.285	.078
	Roy's Largest Root	.285	.078

a. Design: Intercept
Within Subjects Design: Sound + Suppression + Sound * Suppression
b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser
Sound	.954	1.456	2	.483	.956
Suppression	1.000	.000	0	.	1.000
Sound * Suppression	.895	3.436	2	.179	.905

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Epsilon Huynh-Feldt	Epsilon Lower-bound
Sound	1.000	.500
Suppression	1.000	1.000
Sound * Suppression	.956	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.[a]
a. Design: Intercept
Within Subjects Design: Sound + Suppression + Sound * Suppression
b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F
Sound	Sphericity Assumed	.041	2	.021	2.949
	Greenhouse-Geisser	.041	1.912	.022	2.949
	Huynh-Feldt	.041	2.000	.021	2.949
	Lower-bound	.041	1.000	.041	2.949
Error(Sound)	Sphericity Assumed	.450	64	.007	
	Greenhouse-Geisser	.450	61.193	.007	
	Huynh-Feldt	.450	64.000	.007	
	Lower-bound	.450	32.000	.014	
Suppression	Sphericity Assumed	1.620	1	1.620	82.785
	Greenhouse-Geisser	1.620	1.000	1.620	82.785
	Huynh-Feldt	1.620	1.000	1.620	82.785
	Lower-bound	1.620	1.000	1.620	82.785
Error(Suppression)	Sphericity Assumed	.626	32	.020	
	Greenhouse-Geisser	.626	32.000	.020	
	Huynh-Feldt	.626	32.000	.020	
	Lower-bound	.626	32.000	.020	
Sound * Suppression	Sphericity Assumed	.019	2	.009	1.289
	Greenhouse-Geisser	.019	1.810	.010	1.289
	Huynh-Feldt	.019	1.912	.010	1.289
	Lower-bound	.019	1.000	.019	1.289
Error(Sound*Suppression)	Sphericity Assumed	.471	64	.007	
	Greenhouse-Geisser	.471	57.922	.008	
	Huynh-Feldt	.471	61.194	.008	
	Lower-bound	.471	32.000	.015	

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Sig.	Partial Eta Squared
Sound	Sphericity Assumed	.060	.084
	Greenhouse-Geisser	.062	.084
	Huynh-Feldt	.060	.084
	Lower-bound	.096	.084
Error(Sound)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		
Suppression	Sphericity Assumed	.000	.721
	Greenhouse-Geisser	.000	.721
	Huynh-Feldt	.000	.721
	Lower-bound	.000	.721
Error(Suppression)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		
Sound * Suppression	Sphericity Assumed	.283	.039
	Greenhouse-Geisser	.281	.039
	Huynh-Feldt	.282	.039
	Lower-bound	.265	.039
Error(Sound*Suppression)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Sound	Suppression	Type III Sum of Squares	df	Mean Square
Sound	Linear		.031	1	.031
	Quadratic		.010	1	.010
Error(Sound)	Linear		.269	32	.008
	Quadratic		.181	32	.006
Suppression		Linear	1.620	1	1.620
Error(Suppression)		Linear	.626	32	.020
Sound * Suppression	Linear	Linear	.008	1	.008
	Quadratic	Linear	.011	1	.011
Error(Sound*Suppression)	Linear	Linear	.307	32	.010
	Quadratic	Linear	.163	32	.005

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Sound	Suppression	F	Sig.	Partial Eta Squared
Sound	Linear		3.735	.062	.105
	Quadratic		1.783	.191	.053
Error(Sound)	Linear				
	Quadratic				
Suppression		Linear	82.785	.000	.721
Error(Suppression)		Linear			
Sound * Suppression	Linear	Linear	.846	.364	.026
	Quadratic	Linear	2.121	.155	.062
Error(Sound*Suppression)	Linear	Linear			
	Quadratic	Linear			

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	37.930	1	37.930	397.210	.000	.925
Error	3.056	32	.095			

Appendix 6

T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SiL_NS	.5411	33	.18790	.03271
	SiL_S	.3550	33	.14388	.02505
Pair 2	SS_NS	.5487	33	.17560	.03057
	SS_S	.3469	33	.13341	.02322
Pair 3	CS_NS	.4946	33	.14014	.02440
	CS_S	.3398	33	.13986	.02435

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	SiL_NS & SiL_S	33	.425	.014
Pair 2	SS_NS & SS_S	33	.604	.000
Pair 3	CS_NS & CS_S	33	.611	.000

Paired Samples Test

		Paired Differences				
					95% Confidence Interval of the Difference	
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper
Pair 1	SiL_NS - SiL_S	.18615	.18167	.03162	.12173	.25056
Pair 2	SS_NS - SS_S	.20184	.14254	.02481	.15130	.25238
Pair 3	CS_NS - CS_S	.15476	.12345	.02149	.11099	.19854

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	SiL_NS - SiL_S	5.886	32	.000
Pair 2	SS_NS - SS_S	8.134	32	.000
Pair 3	CS_NS - CS_S	7.202	32	.000

Appendix 7

"Holm-Bonferroni Sequential Correction: An EXCEL Calculator" © Justin Gaetano, 2013; correction Paweł Kleka, 2015

				PROCEDURE A		PROCEDURE B	
Instructions	(	*p*	rank	*p* '	outcome	('	outcome
1. Set your omnibus criterion of significance	0.05	0.000	1	0.000	SIG	0.0167	SIG
(α) in the adjacent orange cell.		0.000	2	0.000	SIG	0.0250	SIG
2. Enter your unadjusted *p* -values, ranked		0.000	3	0.000	SIG	0.0500	SIG
smallest (1) to largest (15), in the green cell			4	???	???	???	???
3. Read output from the desired Procedure A			5	???	???	???	???
			6	???	???	???	???
			7	???	???	???	???
			8	???	???	???	???
			9	???	???	???	???
			10	???	???	???	???
Reference			11	???	???	???	???
Holm, S. (1979). A simple sequential rejective			12	???	???	???	???
method procedure. *Scandinavian Journal of*			13	???	???	???	???
Statistics, 6, 65-70.			14	???	???	???	???
			15	???	???	???	???

Procedure A adjusts the *p*- values whilst keeping α constant.
Adjusted *p* -values are provided in the ***p*** ' column.
The outcome column indicates the significance status of each test following Holm's *p* -value correction.
Obtained *p* '-values of 1.000 represent upper-bound estimates: α < *p* ' ≤ 1
If you have incorrectly ranked a value in the ***p*** column, "RANK ERROR" will show up in the **rank** column.

Procedure B adjusts the pairwise criterion of significance (α') corresponding to each uncorrected *p*- value.
Adjusted criteria are provided in the α' column.
The **outcome** column indicates the significance status of each uncorrected *p* -value, given α'.
If you have incorrectly ranked a value in the ***p*** column, "RANK ERROR" will show up in the **rank** column.
Procedure A and B are mathematically equivalent, hence there is no need to report the results of both.

Appendix 8

T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SS_NS	.5487	33	.17560	.03057
	CS_NS	.4946	33	.14014	.02440
Pair 2	SS_S	.3469	33	.13341	.02322
	CS_S	.3398	33	.13986	.02435

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	SS_NS & CS_NS	33	.685	.000
Pair 2	SS_S & CS_S	33	.710	.000

Paired Samples Test

		Paired Differences				
					95% Confidence Interval of the Difference	
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper
Pair 1	SS_NS - CS_NS	.05411	.12942	.02253	.00822	.10000
Pair 2	SS_S - CS_S	.00703	.10431	.01816	-.02995	.04402

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	SS_NS - CS_NS	2.402	32	.022
Pair 2	SS_S - CS_S	.387	32	.701

General Linear Model

Within-Subjects Factors

Measure: MEASURE_1

Sound	Suppression	Dependent Variable
1	1	SiL_NS_RR
	2	SiL_WS_RR
2	1	SS_NS_RR
	2	SS_WS_RR
3	1	CS_NS_RR
	2	CS_WS_RR

Descriptive Statistics

	Mean	Std. Deviation	N
SiL_NS_RR	.0909	.21712	33
SiL_WS_RR	.1288	.18615	33
SS_NS_RR	.0720	.16247	33
SS_WS_RR	.1667	.21800	33
CS_NS_RR	.1591	.21486	33
CS_WS_RR	.1288	.21076	33

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df
Sound	Pillai's Trace	.030	.475[b]	2.000	31.000
	Wilks' Lambda	.970	.475[b]	2.000	31.000
	Hotelling's Trace	.031	.475[b]	2.000	31.000
	Roy's Largest Root	.031	.475[b]	2.000	31.000
Suppression	Pillai's Trace	.063	2.162[b]	1.000	32.000
	Wilks' Lambda	.937	2.162[b]	1.000	32.000
	Hotelling's Trace	.068	2.162[b]	1.000	32.000
	Roy's Largest Root	.068	2.162[b]	1.000	32.000
Sound * Suppression	Pillai's Trace	.080	1.345[b]	2.000	31.000
	Wilks' Lambda	.920	1.345[b]	2.000	31.000
	Hotelling's Trace	.087	1.345[b]	2.000	31.000
	Roy's Largest Root	.087	1.345[b]	2.000	31.000

Multivariate Tests[a]

Effect		Sig.	Partial Eta Squared
Sound	Pillai's Trace	.626	.030
	Wilks' Lambda	.626	.030
	Hotelling's Trace	.626	.030
	Roy's Largest Root	.626	.030
Suppression	Pillai's Trace	.151	.063
	Wilks' Lambda	.151	.063
	Hotelling's Trace	.151	.063
	Roy's Largest Root	.151	.063
Sound * Suppression	Pillai's Trace	.275	.080
	Wilks' Lambda	.275	.080
	Hotelling's Trace	.275	.080
	Roy's Largest Root	.275	.080

a. Design: Intercept

Within Subjects Design: Sound + Suppression + Sound * Suppression

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser
Sound	.945	1.770	2	.413	.947
Suppression	1.000	.000	0	.	1.000
Sound * Suppression	.968	1.019	2	.601	.969

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Epsilon Huynh-Feldt	Epsilon Lower-bound
Sound	1.000	.500
Suppression	1.000	1.000
Sound * Suppression	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.a

a. Design: Intercept

Within Subjects Design: Sound + Suppression + Sound * Suppression

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F
Sound	Sphericity Assumed	.041	2	.020	.512
	Greenhouse-Geisser	.041	1.895	.022	.512
	Huynh-Feldt	.041	2.000	.020	.512
	Lower-bound	.041	1.000	.041	.512
Error(Sound)	Sphericity Assumed	2.553	64	.040	
	Greenhouse-Geisser	2.553	60.636	.042	
	Huynh-Feldt	2.553	64.000	.040	
	Lower-bound	2.553	32.000	.080	
Suppression	Sphericity Assumed	.058	1	.058	2.162
	Greenhouse-Geisser	.058	1.000	.058	2.162
	Huynh-Feldt	.058	1.000	.058	2.162
	Lower-bound	.058	1.000	.058	2.162
Error(Suppression)	Sphericity Assumed	.851	32	.027	
	Greenhouse-Geisser	.851	32.000	.027	
	Huynh-Feldt	.851	32.000	.027	
	Lower-bound	.851	32.000	.027	
Sound * Suppression	Sphericity Assumed	.129	2	.065	1.585
	Greenhouse-Geisser	.129	1.937	.067	1.585
	Huynh-Feldt	.129	2.000	.065	1.585
	Lower-bound	.129	1.000	.129	1.585
Error(Sound*Suppression)	Sphericity Assumed	2.610	64	.041	
	Greenhouse-Geisser	2.610	61.996	.042	
	Huynh-Feldt	2.610	64.000	.041	
	Lower-bound	2.610	32.000	.082	

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Sig.	Partial Eta Squared
Sound	Sphericity Assumed	.601	.016
	Greenhouse-Geisser	.592	.016
	Huynh-Feldt	.601	.016
	Lower-bound	.479	.016
Error(Sound)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		
Suppression	Sphericity Assumed	.151	.063
	Greenhouse-Geisser	.151	.063
	Huynh-Feldt	.151	.063
	Lower-bound	.151	.063
Error(Suppression)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		
Sound * Suppression	Sphericity Assumed	.213	.047
	Greenhouse-Geisser	.214	.047
	Huynh-Feldt	.213	.047
	Lower-bound	.217	.047
Error(Sound*Suppression)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Sound	Suppression	Type III Sum of Squares	df	Mean Square
Sound	Linear		.038	1	.038
	Quadratic		.003	1	.003
Error(Sound)	Linear		1.516	32	.047
	Quadratic		1.037	32	.032
Suppression		Linear	.058	1	.058
Error(Suppression)		Linear	.851	32	.027
Sound * Suppression	Linear	Linear	.038	1	.038
	Quadratic	Linear	.091	1	.091
Error(Sound*Suppression)	Linear	Linear	1.110	32	.035
	Quadratic	Linear	1.500	32	.047

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Sound	Suppression	F	Sig.	Partial Eta Squared
Sound	Linear		.809	.375	.025
	Quadratic		.078	.782	.002
Error(Sound)	Linear				
	Quadratic				
Suppression		Linear	2.162	.151	.063
Error(Suppression)		Linear			
Sound * Suppression	Linear	Linear	1.106	.301	.033
	Quadratic	Linear	1.939	.173	.057
Error(Sound*Suppression)	Linear	Linear			
	Quadratic	Linear			

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	3.063	1	3.063	52.489	.000	.621
Error	1.867	32	.058			

Appendix 10

General Linear Model

Within-Subjects Factors

Measure: MEASURE_1

Sound	Suppression	Dependent Variable
1	1	Sil_NS
	2	Sil_S
2	1	SS_NS
	2	SS_S
3	1	CS_NS
	2	CS_S

Between-Subjects Factors

		Value Label	N
Block_Order	1.00	NS_First	17
	2.00	S_First	16

Descriptive Statistics

	Block_Order	Mean	Std. Deviation	N
Sil_NS	NS_First	.5536	.20796	17
	S_First	.5279	.16978	16
	Total	.5411	.18790	33
Sil_S	NS_First	.3372	.13744	17
	S_First	.3739	.15257	16
	Total	.3550	.14388	33
SS_NS	NS_First	.5557	.16786	17
	S_First	.5413	.18873	16
	Total	.5487	.17560	33
SS_S	NS_First	.3256	.12492	17
	S_First	.3694	.14237	16
	Total	.3469	.13341	33
CS_NS	NS_First	.5021	.15399	17
	S_First	.4866	.12836	16
	Total	.4946	.14014	33
CS_S	NS_First	.3235	.14016	17
	S_First	.3571	.14196	16
	Total	.3398	.13986	33

Box's Test of Equality of Covariance Matrices[a]

Box's M	29.426
F	1.105
df1	21
df2	3504.048
Sig.	.334

Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.[a]

a. Design: Intercept + Block_Order
Within Subjects Design: Sound + Suppression + Sound * Suppression

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df
Sound	Pillai's Trace	.137	2.389[b]	2.000	30.000
	Wilks' Lambda	.863	2.389[b]	2.000	30.000
	Hotelling's Trace	.159	2.389[b]	2.000	30.000
	Roy's Largest Root	.159	2.389[b]	2.000	30.000
Sound * Block_Order	Pillai's Trace	.004	.060[b]	2.000	30.000
	Wilks' Lambda	.996	.060[b]	2.000	30.000
	Hotelling's Trace	.004	.060[b]	2.000	30.000
	Roy's Largest Root	.004	.060[b]	2.000	30.000
Suppression	Pillai's Trace	.732	84.715[b]	1.000	31.000
	Wilks' Lambda	.268	84.715[b]	1.000	31.000
	Hotelling's Trace	2.733	84.715[b]	1.000	31.000
	Roy's Largest Root	2.733	84.715[b]	1.000	31.000
Suppression * Block_Order	Pillai's Trace	.063	2.089[b]	1.000	31.000
	Wilks' Lambda	.937	2.089[b]	1.000	31.000
	Hotelling's Trace	.067	2.089[b]	1.000	31.000
	Roy's Largest Root	.067	2.089[b]	1.000	31.000
Sound * Suppression	Pillai's Trace	.077	1.258[b]	2.000	30.000
	Wilks' Lambda	.923	1.258[b]	2.000	30.000
	Hotelling's Trace	.084	1.258[b]	2.000	30.000
	Roy's Largest Root	.084	1.258[b]	2.000	30.000
Sound * Suppression * Block_Order	Pillai's Trace	.001	.018[b]	2.000	30.000
	Wilks' Lambda	.999	.018[b]	2.000	30.000
	Hotelling's Trace	.001	.018[b]	2.000	30.000
	Roy's Largest Root	.001	.018[b]	2.000	30.000

Multivariate Tests[a]

Effect		Sig.	Partial Eta Squared
Sound	Pillai's Trace	.109	.137
	Wilks' Lambda	.109	.137
	Hotelling's Trace	.109	.137
	Roy's Largest Root	.109	.137
Sound * Block_Order	Pillai's Trace	.942	.004
	Wilks' Lambda	.942	.004
	Hotelling's Trace	.942	.004
	Roy's Largest Root	.942	.004
Suppression	Pillai's Trace	.000	.732
	Wilks' Lambda	.000	.732
	Hotelling's Trace	.000	.732
	Roy's Largest Root	.000	.732
Suppression * Block_Order	Pillai's Trace	.158	.063
	Wilks' Lambda	.158	.063
	Hotelling's Trace	.158	.063
	Roy's Largest Root	.158	.063
Sound * Suppression	Pillai's Trace	.299	.077
	Wilks' Lambda	.299	.077
	Hotelling's Trace	.299	.077
	Roy's Largest Root	.299	.077
Sound * Suppression * Block_Order	Pillai's Trace	.982	.001
	Wilks' Lambda	.982	.001
	Hotelling's Trace	.982	.001
	Roy's Largest Root	.982	.001

a. Design: Intercept + Block_Order

Within Subjects Design: Sound + Suppression + Sound * Suppression

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser
Sound	.953	1.433	2	.488	.955
Suppression	1.000	.000	0	.	1.000
Sound * Suppression	.895	3.314	2	.191	.905

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

	Epsilon	
Within Subjects Effect	Huynh-Feldt	Lower-bound
Sound	1.000	.500
Suppression	1.000	1.000
Sound * Suppression	.989	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.[a]

a. Design: Intercept + Block_Order

Within Subjects Design: Sound + Suppression + Sound * Suppression

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Sound	Sphericity Assumed	.041	2	.021	2.861	.065
	Greenhouse-Geisser	.041	1.911	.022	2.861	.067
	Huynh-Feldt	.041	2.000	.021	2.861	.065
	Lower-bound	.041	1.000	.041	2.861	.101
Sound * Block_Order	Sphericity Assumed	.001	2	.000	.049	.952
	Greenhouse-Geisser	.001	1.911	.000	.049	.947
	Huynh-Feldt	.001	2.000	.000	.049	.952
	Lower-bound	.001	1.000	.001	.049	.827
Error(Sound)	Sphericity Assumed	.450	62	.007		
	Greenhouse-Geisser	.450	59.236	.008		
	Huynh-Feldt	.450	62.000	.007		
	Lower-bound	.450	31.000	.015		
Suppression	Sphericity Assumed	1.603	1	1.603	84.715	.000
	Greenhouse-Geisser	1.603	1.000	1.603	84.715	.000
	Huynh-Feldt	1.603	1.000	1.603	84.715	.000
	Lower-bound	1.603	1.000	1.603	84.715	.000
Suppression * Block_Order	Sphericity Assumed	.040	1	.040	2.089	.158
	Greenhouse-Geisser	.040	1.000	.040	2.089	.158
	Huynh-Feldt	.040	1.000	.040	2.089	.158
	Lower-bound	.040	1.000	.040	2.089	.158
Error(Suppression)	Sphericity Assumed	.587	31	.019		
	Greenhouse-Geisser	.587	31.000	.019		
	Huynh-Feldt	.587	31.000	.019		
	Lower-bound	.587	31.000	.019		
Sound * Suppression	Sphericity Assumed	.019	2	.009	1.240	.296
	Greenhouse-Geisser	.019	1.811	.010	1.240	.294
	Huynh-Feldt	.019	1.979	.010	1.240	.296
	Lower-bound	.019	1.000	.019	1.240	.274
Sound * Suppression * Block_Order	Sphericity Assumed	.000	2	.000	.025	.975
	Greenhouse-Geisser	.000	1.811	.000	.025	.967
	Huynh-Feldt	.000	1.979	.000	.025	.975
	Lower-bound	.000	1.000	.000	.025	.876
Error(Sound*Suppression)	Sphericity Assumed	.470	62	.008		
	Greenhouse-Geisser	.470	56.130	.008		
	Huynh-Feldt	.470	61.334	.008		
	Lower-bound	.470	31.000	.015		

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Partial Eta Squared
Sound	Sphericity Assumed	.085
	Greenhouse-Geisser	.085
	Huynh-Feldt	.085
	Lower-bound	.085
Sound * Block_Order	Sphericity Assumed	.002
	Greenhouse-Geisser	.002
	Huynh-Feldt	.002
	Lower-bound	.002
Error(Sound)	Sphericity Assumed	
	Greenhouse-Geisser	
	Huynh-Feldt	
	Lower-bound	
Suppression	Sphericity Assumed	.732
	Greenhouse-Geisser	.732
	Huynh-Feldt	.732
	Lower-bound	.732
Suppression * Block_Order	Sphericity Assumed	.063
	Greenhouse-Geisser	.063
	Huynh-Feldt	.063
	Lower-bound	.063
Error(Suppression)	Sphericity Assumed	
	Greenhouse-Geisser	
	Huynh-Feldt	
	Lower-bound	
Sound * Suppression	Sphericity Assumed	.038
	Greenhouse-Geisser	.038
	Huynh-Feldt	.038
	Lower-bound	.038
Sound * Suppression * Block_Order	Sphericity Assumed	.001
	Greenhouse-Geisser	.001
	Huynh-Feldt	.001
	Lower-bound	.001
Error(Sound*Suppression)	Sphericity Assumed	
	Greenhouse-Geisser	
	Huynh-Feldt	
	Lower-bound	

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Sound	Suppression	Type III Sum of Squares	df	Mean Square
Sound	Linear		.031	1	.031
	Quadratic		.010	1	.010
Sound * Block_Order	Linear		.000	1	.000
	Quadratic		.001	1	.001
Error(Sound)	Linear		.269	31	.009
	Quadratic		.181	31	.006
Suppression		Linear	1.603	1	1.603
Suppression * Block_Order		Linear	.040	1	.040
Error(Suppression)		Linear	.587	31	.019
Sound * Suppression	Linear	Linear	.008	1	.008
	Quadratic	Linear	.011	1	.011
Sound * Suppression * Block_Order	Linear	Linear	.000	1	.000
	Quadratic	Linear	1.621E-5	1	1.621E-5

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Sound	Suppression	F	Sig.	Partial Eta Squared
Sound	Linear		3.604	.067	.104
	Quadratic		1.757	.195	.054
Sound * Block_Order	Linear		.012	.914	.000
	Quadratic		.104	.750	.003
Error(Sound)	Linear				
	Quadratic				
Suppression		Linear	84.715	.000	.732
Suppression * Block_Order		Linear	2.089	.158	.063
Error(Suppression)		Linear			
Sound * Suppression	Linear	Linear	.810	.375	.025
	Quadratic	Linear	2.048	.162	.062
Sound * Suppression * Block_Order	Linear	Linear	.037	.850	.001
	Quadratic	Linear	.003	.956	.000
Error(Sound*Suppression)	Linear	Linear			
	Quadratic	Linear			

Levene's Test of Equality of Error Variances[a]

		Levene Statistic	df1	df2	Sig.
SiL_NS	Based on Mean	1.127	1	31	.297
	Based on Median	.944	1	31	.339
	Based on Median and with adjusted df	.944	1	30.672	.339
	Based on trimmed mean	1.109	1	31	.300
SiL_S	Based on Mean	1.064	1	31	.310
	Based on Median	1.085	1	31	.306
	Based on Median and with adjusted df	1.085	1	29.365	.306
	Based on trimmed mean	1.006	1	31	.324
SS_NS	Based on Mean	.032	1	31	.859
	Based on Median	.009	1	31	.927
	Based on Median and with adjusted df	.009	1	29.298	.927
	Based on trimmed mean	.026	1	31	.874
SS_S	Based on Mean	.830	1	31	.369
	Based on Median	.858	1	31	.361
	Based on Median and with adjusted df	.858	1	30.830	.362
	Based on trimmed mean	.835	1	31	.368
CS_NS	Based on Mean	.148	1	31	.704
	Based on Median	.106	1	31	.747
	Based on Median and with adjusted df	.106	1	27.403	.748
	Based on trimmed mean	.148	1	31	.703
CS_S	Based on Mean	.006	1	31	.937
	Based on Median	.004	1	31	.949
	Based on Median and with adjusted df	.004	1	30.731	.949
	Based on trimmed mean	.003	1	31	.957

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.[a]

a. Design: Intercept + Block_Order

Within Subjects Design: Sound + Suppression + Sound * Suppression

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	37.920	1	37.920	385.297	.000	.926
Block_Order	.005	1	.005	.048	.828	.002
Error	3.051	31	.098			

Appendix 11

General Linear Model

Descriptive Statistics

	Mean	Std. Deviation	N
Sil_T1	.5671	.27078	33
Sil_T2	.4719	.26842	33
Sil_T3	.4675	.28183	33
Sil_T4	.5887	.30254	33
Sil_T5	.5628	.29220	33
Sil_T6	.5671	.29984	33
Sil_T7	.5541	.32490	33
Sil_T8	.5498	.33904	33
SS_T1	.5325	.33933	33
SS_T2	.4892	.28354	33
SS_T3	.4805	.25208	33
SS_T4	.4675	.32591	33
SS_T5	.5152	.34058	33
SS_T6	.6494	.24508	33
SS_T7	.6667	.26885	33
SS_T8	.5887	.30042	33
CS_T1	.5152	.24728	33
CS_T2	.4589	.28293	33
CS_T3	.4632	.24492	33
CS_T4	.5541	.27608	33
CS_T5	.4762	.29378	33
CS_T6	.4978	.29260	33
CS_T7	.4892	.29021	33
CS_T8	.5022	.31364	33

Within-Subjects Factors

Measure: MEASURE_1

Sound	Trial_Order	Dependent Variable
1	1	Sil_T1
	2	Sil_T2
	3	Sil_T3
	4	Sil_T4
	5	Sil_T5
	6	Sil_T6
	7	Sil_T7
	8	Sil_T8
2	1	SS_T1
	2	SS_T2
	3	SS_T3
	4	SS_T4
	5	SS_T5
	6	SS_T6
	7	SS_T7
	8	SS_T8
3	1	CS_T1
	2	CS_T2
	3	CS_T3
	4	CS_T4
	5	CS_T5
	6	CS_T6
	7	CS_T7
	8	CS_T8

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
Sound	Pillai's Trace	.155	2.847[b]	2.000	31.000	.073
	Wilks' Lambda	.845	2.847[b]	2.000	31.000	.073
	Hotelling's Trace	.184	2.847[b]	2.000	31.000	.073
	Roy's Largest Root	.184	2.847[b]	2.000	31.000	.073
Trial_Order	Pillai's Trace	.417	2.655[b]	7.000	26.000	.033
	Wilks' Lambda	.583	2.655[b]	7.000	26.000	.033
	Hotelling's Trace	.715	2.655[b]	7.000	26.000	.033
	Roy's Largest Root	.715	2.655[b]	7.000	26.000	.033
Sound * Trial_Order	Pillai's Trace	.437	1.052[b]	14.000	19.000	.450
	Wilks' Lambda	.563	1.052[b]	14.000	19.000	.450
	Hotelling's Trace	.775	1.052[b]	14.000	19.000	.450
	Roy's Largest Root	.775	1.052[b]	14.000	19.000	.450

Multivariate Tests[a]

Effect		Partial Eta Squared
Sound	Pillai's Trace	.155
	Wilks' Lambda	.155
	Hotelling's Trace	.155
	Roy's Largest Root	.155
Trial_Order	Pillai's Trace	.417
	Wilks' Lambda	.417
	Hotelling's Trace	.417
	Roy's Largest Root	.417
Sound * Trial_Order	Pillai's Trace	.437
	Wilks' Lambda	.437
	Hotelling's Trace	.437
	Roy's Largest Root	.437

a. Design: Intercept
Within Subjects Design: Sound + Trial_Order + Sound * Trial_Order
b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser
Sound	.927	2.336	2	.311	.932
Trial_Order	.215	45.225	27	.016	.694
Sound * Trial_Order	.013	118.448	104	.187	.631

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Epsilon	
	Huynh-Feldt	Lower-bound
Sound	.988	.500
Trial_Order	.834	.143
Sound * Trial_Order	.893	.071

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.[a]

a. Design: Intercept

Within Subjects Design: Sound + Trial_Order + Sound * Trial_Order

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F
Sound	Sphericity Assumed	.453	2	.227	3.250
	Greenhouse-Geisser	.453	1.865	.243	3.250
	Huynh-Feldt	.453	1.976	.229	3.250
	Lower-bound	.453	1.000	.453	3.250
Error(Sound)	Sphericity Assumed	4.463	64	.070	
	Greenhouse-Geisser	4.463	59.668	.075	
	Huynh-Feldt	4.463	63.216	.071	
	Lower-bound	4.463	32.000	.139	
Trial_Order	Sphericity Assumed	1.049	7	.150	2.260
	Greenhouse-Geisser	1.049	4.861	.216	2.260
	Huynh-Feldt	1.049	5.838	.180	2.260
	Lower-bound	1.049	1.000	1.049	2.260
Error(Trial_Order)	Sphericity Assumed	14.854	224	.066	
	Greenhouse-Geisser	14.854	155.562	.095	
	Huynh-Feldt	14.854	186.801	.080	
	Lower-bound	14.854	32.000	.464	
Sound * Trial_Order	Sphericity Assumed	1.031	14	.074	1.149
	Greenhouse-Geisser	1.031	8.839	.117	1.149
	Huynh-Feldt	1.031	12.508	.082	1.149
	Lower-bound	1.031	1.000	1.031	1.149
Error(Sound*Trial_Order)	Sphericity Assumed	28.719	448	.064	
	Greenhouse-Geisser	28.719	282.848	.102	
	Huynh-Feldt	28.719	400.241	.072	
	Lower-bound	28.719	32.000	.897	

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Sig.	Partial Eta Squared
Sound	Sphericity Assumed	.045	.092
	Greenhouse-Geisser	.049	.092
	Huynh-Feldt	.046	.092
	Lower-bound	.081	.092
Error(Sound)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		
Trial_Order	Sphericity Assumed	.031	.066
	Greenhouse-Geisser	.053	.066
	Huynh-Feldt	.041	.066
	Lower-bound	.143	.066
Error(Trial_Order)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		
Sound * Trial_Order	Sphericity Assumed	.313	.035
	Greenhouse-Geisser	.329	.035
	Huynh-Feldt	.317	.035
	Lower-bound	.292	.035
Error(Sound*Trial_Order)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Sound	Trial_Order	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Sound	Linear		.286	1	.286	3.278	.080	.093
	Quadratic		.167	1	.167	3.203	.083	.091
Error(Sound)	Linear		2.791	32	.087			
	Quadratic		1.673	32	.052			
Trial_Order		Linear	.404	1	.404	3.402	.074	.096
		Quadratic	.034	1	.034	.518	.477	.016
		Cubic	.432	1	.432	6.362	.017	.166
		Order 4	.026	1	.026	.388	.538	.012
		Order 5	.024	1	.024	.497	.486	.015
		Order 6	.000	1	.000	.006	.937	.000
		Order 7	.128	1	.128	2.716	.109	.078
Error(Trial_Order)		Linear	3.802	32	.119			
		Quadratic	2.089	32	.065			
		Cubic	2.174	32	.068			
		Order 4	2.135	32	.067			
		Order 5	1.543	32	.048			
		Order 6	1.599	32	.050			
		Order 7	1.512	32	.047			
Sound * Trial_Order	Linear	Linear	.022	1	.022	.606	.442	.019
		Quadratic	.000	1	.000	.003	.958	.000
		Cubic	.051	1	.051	1.104	.301	.033
		Order 4	.008	1	.008	.114	.738	.004
		Order 5	.003	1	.003	.040	.843	.001
		Order 6	.003	1	.003	.039	.845	.001
		Order 7	.003	1	.003	.061	.807	.002
	Quadratic	Linear	.299	1	.299	4.756	.037	.129
		Quadratic	.063	1	.063	.953	.336	.029
		Cubic	.104	1	.104	1.526	.226	.046

		Order 4	.363	1	.363	7.509	.010	.190
		Order 5	.009	1	.009	.214	.647	.007
		Order 6	.074	1	.074	.953	.336	.029
		Order 7	.029	1	.029	.466	.500	.014
Error(Sound*Trial_Order)	Linear	Linear	1.177	32	.037			
		Quadratic	2.979	32	.093			
		Cubic	1.468	32	.046			
		Order 4	2.312	32	.072			
		Order 5	2.641	32	.083			
		Order 6	2.804	32	.088			
		Order 7	1.716	32	.054			
	Quadratic	Linear	2.011	32	.063			
		Quadratic	2.109	32	.066			
		Cubic	2.180	32	.068			
		Order 4	1.545	32	.048			
		Order 5	1.317	32	.041			
		Order 6	2.469	32	.077			
		Order 7	1.990	32	.062			

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	220.913	1	220.913	404.023	.000	.927
Error	17.497	32	.547			

Means

Case Processing Summary

	Cases					
	Included		Excluded		Total	
	N	Percent	N	Percent	N	Percent
Age * Gender	18	100.0%	0	0.0%	18	100.0%

Report

Age

Gender	Mean	N	Std. Deviation
Female	29.5455	11	10.52011
Male	27.4286	7	14.60430
Total	28.7222	18	11.89565

Appendix 13

<u>Short-Term Memory for Non-Iconic Gestures: Information Sheet</u>

<u>Overview of Experiment</u>

The aim of this study is to examine the ability to remember sequences of non-iconic gestures (movements). Upon providing consent, you will be asked to complete a computer-based task which involves sequences (made up of short videos) depicting these gestures. Some of the sequences will be silent, while others will contain irrelevant background sound (played through headphones) which you will be instructed to ignore and will not be tested on. In one of the blocks, you will also be required to say the word "*saxophone*" aloud at a rate of once per second. The goal of the task is to reproduce the order in which the movements appeared. The study should take no longer than one hour, and participation is entirely voluntary.

Please note, should you experience any issues or difficulty during the experiment, please inform the experimenter as soon as they arise.

<u>Requirements</u>

You must have normal or corrected to normal vision and hearing.

You must not be familiar with sign language.

<u>Compensation</u>

For taking part in this study, you will be awarded four SONA points (for School of Psychology students) or a £5 Amazon voucher.

Should you wish to take part in the study or require further information, please contact the researcher:

Researcher:	Director of Studies:	First Supervisor:	Second Supervisor:
Stuart Moore	Dr John Marsh	Professor Linden Ball	Dr Reyhan Furman
SBMoore@uclan.ac.uk	JEMarsh@uclan.ac.uk	LBall@uclan.ac.uk	RFurman@uclan.ac.uk

If you have any concerns about the research that you wish to raise with somebody independent of the research team, contact the University Officer for Ethics (OfficerForEthics@uclan.ac.uk)

Appendix 14

Short-Term Memory for Non-Iconic Gestures: Debrief Sheet

First, I would like to take this opportunity to thank you for taking part in my study and I will now explain the purpose of this experiment.

The data collected today will be used to examine serial recall performance for non-iconic gestures (movements). As you know, serial recall tasks involve reproducing a sequence of items in the order presented and while there is a significant amount of research relating to serial recall performance for verbal (e.g., letters, digits, words) and spatial (e.g., locations) items, there is a lack of research relating to performance for movements. It has been suggested that the ability to maintain items in the presented order is facilitated by the same mechanism regardless of the nature of the information (e.g., verbal, spatial, manual-gestural; Jones, Farrand, Stuart, & Morris, 1995). Therefore, serial recall performance for each of these types of information should exhibit the same pattern however, there has been no research regarding performance for movements.

This can be further tested with the addition of articulatory suppression and irrelevant sound. Articulatory suppression prevents rehearsal of verbal information, thus resulting in reduced serial recall performance. While this is used mostly in verbal serial recall studies, it was employed in this study to prevent verbal recoding of the movements (e.g., giving each movement a name) and it has also been shown to disrupt performance in spatial serial recall (Jones et al. 1995). Furthermore, the use of irrelevant sound will allow testing of the changing-state hypothesis (Jones & Macken, 1993, 1995, Jones, Madden, & Miles, 1992; Macken & Jones, 1995), where irrelevant sound that changes from item to item (i.e., a, b, c, d…) disrupts serial recall performance to a greater extent than irrelevant sound that stays the same (i.e., a, a, a, a). This is due to both the serial recall task and the changing-state irrelevant sound containing information relating to the order of the items (known as interference by process; e.g., Beaman & Jones, 1997).

Data obtained from a previous experiment I carried out using meaningless movements displayed similar characteristics to that of verbal serial recall thus, this experiment was added to investigate the possibility that participants were utilising a process called verbal recoding, whereby a name will be given to the movement, aiding in performance. The movements used in the experiment you just undertook are classed as "non-iconic" movements, meaning that they are extremely difficult to verbally recode. I would like to remind you that this is the final opportunity to withdraw from the study as your data will be anonymised when you leave the session. Should you have any follow up questions or queries, please contact the researcher or alternatively, the supervisory team.

Researcher:	Director of Studies:	First Supervisor:	Second Supervisor:
Stuart Moore	Dr John Marsh	Professor Linden Ball	Dr Reyhan Furman
SBMoore@uclan.ac.uk	JEMarsh@uclan.ac.uk	LBall@uclan.ac.uk	RFurman@uclan.ac.uk

If you have any concerns about the research that you wish to raise with somebody independent of the research team, contact the University Officer for Ethics (OfficerForEthics@uclan.ac.uk)

Appendix 15

General Linear Model

Within-Subjects Factors

Measure: MEASURE_1

Sound	Supp	Dependent Variable
1	1	SiL_NS
	2	SiL_WS
2	1	SS_NS
	2	SS_WS
3	1	CS_NS
	2	CS_WS

Descriptive Statistics

	Mean	Std. Deviation	N
SiL_NS	.3278	.06763	18
SiL_WS	.2794	.10455	18
SS_NS	.3310	.11058	18
SS_WS	.2659	.09440	18
CS_NS	.2960	.06057	18
CS_WS	.2825	.09483	18

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
Sound	Pillai's Trace	.070	.606[b]	2.000	16.000	.558
	Wilks' Lambda	.930	.606[b]	2.000	16.000	.558
	Hotelling's Trace	.076	.606[b]	2.000	16.000	.558
	Roy's Largest Root	.076	.606[b]	2.000	16.000	.558
Supp	Pillai's Trace	.334	8.508[b]	1.000	17.000	.010
	Wilks' Lambda	.666	8.508[b]	1.000	17.000	.010
	Hotelling's Trace	.500	8.508[b]	1.000	17.000	.010
	Roy's Largest Root	.500	8.508[b]	1.000	17.000	.010
Sound * Supp	Pillai's Trace	.096	.852[b]	2.000	16.000	.445
	Wilks' Lambda	.904	.852[b]	2.000	16.000	.445
	Hotelling's Trace	.107	.852[b]	2.000	16.000	.445
	Roy's Largest Root	.107	.852[b]	2.000	16.000	.445

Multivariate Tests[a]

Effect		Partial Eta Squared
Sound	Pillai's Trace	.070
	Wilks' Lambda	.070
	Hotelling's Trace	.070
	Roy's Largest Root	.070
Supp	Pillai's Trace	.334
	Wilks' Lambda	.334
	Hotelling's Trace	.334
	Roy's Largest Root	.334
Sound * Supp	Pillai's Trace	.096
	Wilks' Lambda	.096
	Hotelling's Trace	.096
	Roy's Largest Root	.096

a. Design: Intercept

Within Subjects Design: Sound + Supp + Sound * Supp

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser
Sound	.985	.236	2	.889	.986
Supp	1.000	.000	0	.	1.000
Sound * Supp	.862	2.368	2	.306	.879

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Epsilon Huynh-Feldt	Lower-bound
Sound	1.000	.500
Supp	1.000	1.000
Sound * Supp	.973	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.[a]

a. Design: Intercept

Within Subjects Design: Sound + Supp + Sound * Supp

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F
Sound	Sphericity Assumed	.004	2	.002	.606
	Greenhouse-Geisser	.004	1.971	.002	.606
	Huynh-Feldt	.004	2.000	.002	.606
	Lower-bound	.004	1.000	.004	.606
Error(Sound)	Sphericity Assumed	.106	34	.003	
	Greenhouse-Geisser	.106	33.508	.003	
	Huynh-Feldt	.106	34.000	.003	
	Lower-bound	.106	17.000	.006	
Supp	Sphericity Assumed	.048	1	.048	8.508
	Greenhouse-Geisser	.048	1.000	.048	8.508
	Huynh-Feldt	.048	1.000	.048	8.508
	Lower-bound	.048	1.000	.048	8.508
Error(Supp)	Sphericity Assumed	.097	17	.006	
	Greenhouse-Geisser	.097	17.000	.006	
	Huynh-Feldt	.097	17.000	.006	
	Lower-bound	.097	17.000	.006	
Sound * Supp	Sphericity Assumed	.012	2	.006	1.225
	Greenhouse-Geisser	.012	1.758	.007	1.225
	Huynh-Feldt	.012	1.945	.006	1.225
	Lower-bound	.012	1.000	.012	1.225
Error(Sound*Supp)	Sphericity Assumed	.173	34	.005	
	Greenhouse-Geisser	.173	29.888	.006	
	Huynh-Feldt	.173	33.066	.005	
	Lower-bound	.173	17.000	.010	

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Sig.	Partial Eta Squared
Sound	Sphericity Assumed	.551	.034
	Greenhouse-Geisser	.549	.034
	Huynh-Feldt	.551	.034
	Lower-bound	.447	.034
Error(Sound)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		
Supp	Sphericity Assumed	.010	.334
	Greenhouse-Geisser	.010	.334
	Huynh-Feldt	.010	.334
	Lower-bound	.010	.334
Error(Supp)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		
Sound * Supp	Sphericity Assumed	.306	.067
	Greenhouse-Geisser	.304	.067
	Huynh-Feldt	.306	.067
	Lower-bound	.284	.067
Error(Sound*Supp)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Sound	Supp	Type III Sum of Squares	df	Mean Square	F
Sound	Linear		.004	1	.004	1.283
	Quadratic		9.448E-5	1	9.448E-5	.028
Error(Sound)	Linear		.049	17	.003	
	Quadratic		.057	17	.003	
Supp		Linear	.048	1	.048	8.508
Error(Supp)		Linear	.097	17	.006	
Sound * Supp	Linear	Linear	.005	1	.005	1.227
	Quadratic	Linear	.007	1	.007	1.224
Error(Sound*Supp)	Linear	Linear	.076	17	.004	
	Quadratic	Linear	.097	17	.006	

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Sound	Supp	Sig.	Partial Eta Squared
Sound	Linear		.273	.070
	Quadratic		.869	.002
Error(Sound)	Linear			
	Quadratic			
Supp		Linear	.010	.334
Error(Supp)		Linear		
Sound * Supp	Linear	Linear	.283	.067
	Quadratic	Linear	.284	.067
Error(Sound*Supp)	Linear	Linear		
	Quadratic	Linear		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	9.532	1	9.532	350.285	.000	.954
Error	.463	17	.027			

Appendix 16

T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SiL_NS	.3278	18	.06763	.01594
	SiL_WS	.2794	18	.10455	.02464
Pair 2	SS_NS	.3310	18	.11058	.02606
	SS_WS	.2659	18	.09440	.02225
Pair 3	CS_NS	.2960	18	.06057	.01428
	CS_WS	.2825	18	.09483	.02235

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	SiL_NS & SiL_WS	18	.446	.064
Pair 2	SS_NS & SS_WS	18	.399	.101
Pair 3	CS_NS & CS_WS	18	.255	.308

Paired Samples Test

		Paired Differences				
					95% Confidence Interval of the Difference	
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper
Pair 1	SiL_NS - SiL_WS	.04841	.09591	.02261	.00072	.09611
Pair 2	SS_NS - SS_WS	.06508	.11315	.02667	.00881	.12135
Pair 3	CS_NS - CS_WS	.01349	.09867	.02326	-.03557	.06256

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	SiL_NS - SiL_WS	2.142	17	.047
Pair 2	SS_NS - SS_WS	2.440	17	.026
Pair 3	CS_NS - CS_WS	.580	17	.569

"Holm-Bonferroni Sequential Correction: An EXCEL Calculator" © Justin Gaetano, 2013; correction Paweł Kleka, 2015

				PROCEDURE A		PROCEDURE B	
Instructions	〈	p	rank	p '	outcome	〈 '	outcome
1. Set your omnibus criterion of significance (α) in the	0.05	0.026	1	0.078	NON SIG	0.0167	NON SIG
adjacent orange cell.		0.047	2	0.094	NON SIG	0.0167	NON SIG
2. Enter your unadjusted p -values, ranked smallest (1)		0.569	3	0.569	NON SIG	0.0167	NON SIG
to largest (15), in the green cell range.			4	???	???	???	???
3. Read output from the desired Procedure A or B box -			5	???	???	???	???
			6	???	???	???	???
			7	???	???	???	???
			8	???	???	???	???
			9	???	???	???	???
			10	???	???	???	???
Reference			11	???	???	???	???
Holm, S. (1979). A simple sequential rejective method			12	???	???	???	???
procedure. *Scandinavian Journal of Statistics, 6*, 65-			13	???	???	???	???
70.			14	???	???	???	???
			15	???	???	???	???

Procedure A adjusts the p- values whilst keeping α constant.
Adjusted p -values are provided in the **p '** column.
The outcome column indicates the significance status of each test following Holm's p -value correction.
Obtained p '-values of 1.000 represent upper-bound estimates: α < p ' δ 1
If you have incorrectly ranked a value in the **p** column, "RANK ERROR" will show up in the **rank** column.

Procedure B adjusts the pairwise criterion of significance (α') corresponding to each uncorrected p- value.
Adjusted criteria are provided in the α' column.
The **outcome** column indicates the significance status of each uncorrected p -value, given α'.
If you have incorrectly ranked a value in the **p** column, "RANK ERROR" will show up in the **rank** column.
Procedure A and B are mathematically equivalent, hence there is no need to report the results of both.

Appendix 17

T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SS_NS	.3310	18	.11058	.02606
	CS_NS	.2960	18	.06057	.01428
Pair 2	SS_WS	.2659	18	.09440	.02225
	CS_WS	.2825	18	.09483	.02235

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	SS_NS & CS_NS	18	.373	.128
Pair 2	SS_WS & CS_WS	18	.444	.065

Paired Samples Test

		Paired Differences				
					95% Confidence Interval of the Difference	
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper
Pair 1	SS_NS - CS_NS	.03492	.10443	.02461	-.01701	.08685
Pair 2	SS_WS - CS_WS	-.01667	.09973	.02351	-.06626	.03293

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	SS_NS - CS_NS	1.419	17	.174
Pair 2	SS_WS - CS_WS	-.709	17	.488

Appendix 18

General Linear Model

Within-Subjects Factors

Measure: MEASURE_1

Sound	Suppression	Dependent Variable
1	1	SiL_NS_RR
	2	SiL_WS_RR
2	1	SS_NS_RR
	2	SS_WS_RR
3	1	CS_NS_RR
	2	CS_WS_RR

Descriptive Statistics

	Mean	Std. Deviation	N
SiL_NS_RR	.0833	.20364	18
SiL_WS_RR	.0111	.14907	18
SS_NS_RR	.1444	.14642	18
SS_WS_RR	.1667	.20292	18
CS_NS_RR	.1389	.19140	18
CS_WS_RR	.1222	.15168	18

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df
Sound	Pillai's Trace	.529	9.002[b]	2.000	16.000
	Wilks' Lambda	.471	9.002[b]	2.000	16.000
	Hotelling's Trace	1.125	9.002[b]	2.000	16.000
	Roy's Largest Root	1.125	9.002[b]	2.000	16.000
Suppression	Pillai's Trace	.032	.567[b]	1.000	17.000
	Wilks' Lambda	.968	.567[b]	1.000	17.000
	Hotelling's Trace	.033	.567[b]	1.000	17.000
	Roy's Largest Root	.033	.567[b]	1.000	17.000
Sound * Suppression	Pillai's Trace	.047	.397[b]	2.000	16.000
	Wilks' Lambda	.953	.397[b]	2.000	16.000
	Hotelling's Trace	.050	.397[b]	2.000	16.000
	Roy's Largest Root	.050	.397[b]	2.000	16.000

Multivariate Tests[a]

Effect		Sig.	Partial Eta Squared
Sound	Pillai's Trace	.002	.529
	Wilks' Lambda	.002	.529
	Hotelling's Trace	.002	.529
	Roy's Largest Root	.002	.529
Suppression	Pillai's Trace	.462	.032
	Wilks' Lambda	.462	.032
	Hotelling's Trace	.462	.032
	Roy's Largest Root	.462	.032
Sound * Suppression	Pillai's Trace	.679	.047
	Wilks' Lambda	.679	.047
	Hotelling's Trace	.679	.047
	Roy's Largest Root	.679	.047

a. Design: Intercept

Within Subjects Design: Sound + Suppression + Sound * Suppression

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser
Sound	.714	5.379	2	.068	.778
Suppression	1.000	.000	0	.	1.000
Sound * Suppression	.901	1.675	2	.433	.910

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

	Epsilon	
Within Subjects Effect	Huynh-Feldt	Lower-bound
Sound	.842	.500
Suppression	1.000	1.000
Sound * Suppression	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.[a]

a. Design: Intercept

Within Subjects Design: Sound + Suppression + Sound * Suppression

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F
Sound	Sphericity Assumed	.232	2	.116	4.536
	Greenhouse-Geisser	.232	1.556	.149	4.536
	Huynh-Feldt	.232	1.684	.138	4.536
	Lower-bound	.232	1.000	.232	4.536
Error(Sound)	Sphericity Assumed	.868	34	.026	
	Greenhouse-Geisser	.868	26.449	.033	
	Huynh-Feldt	.868	28.624	.030	
	Lower-bound	.868	17.000	.051	
Suppression	Sphericity Assumed	.013	1	.013	.567
	Greenhouse-Geisser	.013	1.000	.013	.567
	Huynh-Feldt	.013	1.000	.013	.567
	Lower-bound	.013	1.000	.013	.567
Error(Suppression)	Sphericity Assumed	.400	17	.024	
	Greenhouse-Geisser	.400	17.000	.024	
	Huynh-Feldt	.400	17.000	.024	
	Lower-bound	.400	17.000	.024	
Sound * Suppression	Sphericity Assumed	.041	2	.020	.536
	Greenhouse-Geisser	.041	1.819	.022	.536
	Huynh-Feldt	.041	2.000	.020	.536
	Lower-bound	.041	1.000	.041	.536
Error(Sound*Suppression)	Sphericity Assumed	1.286	34	.038	
	Greenhouse-Geisser	1.286	30.925	.042	
	Huynh-Feldt	1.286	34.000	.038	
	Lower-bound	1.286	17.000	.076	

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Sig.	Partial Eta Squared
Sound	Sphericity Assumed	.018	.211
	Greenhouse-Geisser	.028	.211
	Huynh-Feldt	.024	.211
	Lower-bound	.048	.211
Error(Sound)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		
Suppression	Sphericity Assumed	.462	.032
	Greenhouse-Geisser	.462	.032
	Huynh-Feldt	.462	.032
	Lower-bound	.462	.032
Error(Suppression)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		
Sound * Suppression	Sphericity Assumed	.590	.031
	Greenhouse-Geisser	.574	.031
	Huynh-Feldt	.590	.031
	Lower-bound	.474	.031
Error(Sound*Suppression)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Sound	Suppression	Type III Sum of Squares	df	Mean Square
Sound	Linear		.125	1	.125
	Quadratic		.107	1	.107
Error(Sound)	Linear		.490	17	.029
	Quadratic		.378	17	.022
Suppression		Linear	.013	1	.013
Error(Suppression)		Linear	.400	17	.024
Sound * Suppression	Linear	Linear	.014	1	.014
	Quadratic	Linear	.027	1	.027
Error(Sound*Suppression)	Linear	Linear	.511	17	.030
	Quadratic	Linear	.775	17	.046

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Sound	Suppression	F	Sig.	Partial Eta Squared
Sound	Linear		4.337	.053	.203
	Quadratic		4.793	.043	.220
Error(Sound)	Linear				
	Quadratic				
Suppression		Linear	.567	.462	.032
Error(Suppression)		Linear			
Sound * Suppression	Linear	Linear	.462	.506	.026
	Quadratic	Linear	.585	.455	.033
Error(Sound*Suppression)	Linear	Linear			
	Quadratic	Linear			

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1.333	1	1.333	37.363	.000	.687
Error	.607	17	.036			

Appendix 19

T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Sil_NS_RR	.0833	18	.20364	.04800
	SS_NS_RR	.1444	18	.14642	.03451
Pair 2	Sil_NS_RR	.0833	18	.20364	.04800
	CS_NS_RR	.1389	18	.19140	.04511
Pair 3	SS_NS_RR	.1444	18	.14642	.03451
	CS_NS_RR	.1389	18	.19140	.04511
Pair 4	Sil_WS_RR	.0111	18	.14907	.03514
	SS_WS_RR	.1667	18	.20292	.04783
Pair 5	Sil_WS_RR	.0111	18	.14907	.03514
	CS_WS_RR	.1222	18	.15168	.03575
Pair 6	SS_WS_RR	.1667	18	.20292	.04783
	CS_WS_RR	.1222	18	.15168	.03575

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Sil_NS_RR & SS_NS_RR	18	-.289	.244
Pair 2	Sil_NS_RR & CS_NS_RR	18	.003	.992
Pair 3	SS_NS_RR & CS_NS_RR	18	-.086	.734
Pair 4	Sil_WS_RR & SS_WS_RR	18	.324	.189
Pair 5	Sil_WS_RR & CS_WS_RR	18	.119	.640
Pair 6	SS_WS_RR & CS_WS_RR	18	-.185	.463

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	Sil_NS_RR - SS_NS_RR	-.06111	.28313	.06673	-.20191	.07969	-.916	17	.373
Pair 2	Sil_NS_RR - CS_NS_RR	-.05556	.27912	.06579	-.19436	.08325	-.844	17	.410
Pair 3	SS_NS_RR - CS_NS_RR	.00556	.25082	.05912	-.11917	.13028	.094	17	.926
Pair 4	Sil_WS_RR - SS_WS_RR	-.15556	.20926	.04932	-.25962	-.05149	-3.154	17	.006
Pair 5	Sil_WS_RR - CS_WS_RR	-.11111	.19967	.04706	-.21041	-.01182	-2.361	17	.030
Pair 6	SS_WS_RR - CS_WS_RR	.04444	.27487	.06479	-.09225	.18114	.686	17	.502

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				PROCEDURE A		PROCEDURE B	
Instructions	⟨	*p*	rank	*p'*	outcome	⟨'	outcome
1. Set your omnibus criterion of significance	0.05	0.006	1	0.036	SIG	0.0083	SIG
(α) in the adjacent orange cell.		0.030	2	0.150	NON SIG	0.0100	NON SIG
2. Enter your unadjusted *p*-values, ranked		0.373	3	1.000	NON SIG	0.0100	NON SIG
smallest (1) to largest (15), in the green cell		0.410	4	1.000	NON SIG	0.0100	NON SIG
3. Read output from the desired Procedure A		0.502	5	1.000	NON SIG	0.0100	NON SIG
		0.926	6	1.000	NON SIG	0.0100	NON SIG
			7	???	???	???	???
			8	???	???	???	???
			9	???	???	???	???
			10	???	???	???	???
Reference			11	???	???	???	???
Holm, S. (1979). A simple sequential rejective			12	???	???	???	???
method procedure. *Scandinavian Journal of*			13	???	???	???	???
Statistics, 6, 65-70.			14	???	???	???	???
			15	???	???	???	???

Procedure A adjusts the *p*-values whilst keeping α constant.
Adjusted *p*-values are provided in the ***p'*** column.
The outcome column indicates the significance status of each test following Holm's *p*-value correction.
Obtained *p'*-values of 1.000 represent upper-bound estimates: α < *p'* δ 1
If you have incorrectly ranked a value in the ***p*** column, "RANK ERROR" will show up in the **rank** column.

Procedure B adjusts the pairwise criterion of significance (α') corresponding to each uncorrected *p*-value.
Adjusted criteria are provided in the α' column.
The **outcome** column indicates the significance status of each uncorrected *p*-value, given α'.
If you have incorrectly ranked a value in the ***p*** column, "RANK ERROR" will show up in the **rank** column.
Procedure A and B are mathematically equivalent, hence there is no need to report the results of both.