The Functional Working Memory Architecture of Visual Change Detection Tasks: Are These Tasks Visual Domain Specific?

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Abstract

This thesis aimed to investigate the functional working memory architecture of two visual change detection tasks; a quantitative colour change detection task (Luck & Vogel, 1997) and a qualitative Size Just Noticeable Differences task (Phillips & Hamilton, 2001). Domain specific approaches to the working memory architecture proposed the use of visual only representations (Baddeley, 2012), however, multicomponent approaches, have suggested the use of both visual and verbal representations (Logie, 2011; Brown & Wesley, 2013). The current thesis examined this issue using six experimental investigations. The first two studies piloted the two tasks. Two consecutive studies used dual task interference protocols to investigate the working memory architecture of each change detection task before study five provided electrophysiological data. The final study of the thesis then aimed to discover if both change detection tasks could predict verbal and non-verbal intelligence in children aged 7-13 years. The pilot investigations indicated the appropriate array size and shape size stimuli to use for the remainder of the thesis. Both dual task studies then indicated the use of visual and verbal representations within each change detection task, however qualitative smaller changes were not susceptible to verbal interference. Further evidence was provided from the electrophysiological data presenting activation of the semantic N400 and visual specific N200 in both change detection procedures, but this was significantly reduced in the small change, qualitative stimuli. Results of the final developmental investigation also indicated a more visual specific approach to the qualitative task; leading the current thesis to propose a context-dependent multicomponent approach to change detection protocols. Results are discussed in relation to the multicomponent and attentional models of working memory.

Contents

Chapter 2: Thesis Methodologies, Aims and Rationales

Chapter 3: Evaluating the Luck and Vogel Visual Change Detection Procedure

Chapter 4: Qualitative Preliminary Studies

Chapter 5: Quantitative Dual Task Experiment

Chapter 6: Qualitative Interference Study 4a and 4b

List of Tables

List of Figures

List of Appendices

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Authors Declaration

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work. I also confirm that this work fully acknowledges opinions, ideas and contributions from the work of others.

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AIMS OF THE LITERATURE REVIEW

Two theoretical approaches of the working memory architecture have provided us with discussions of how a visual working memory task may utilise specific information use during the encoding and retrieval of visual items. Baddeley and Hitch (1974) had originally proposed a three component model, with an updated version of this model (Baddeley, 2012) suggesting the clear separation of a Visuospatial Sketch Pad, Phonological Loop and Central Executive. In more recent years, Logie's (2011) update of the working memory architecture details how the visual and verbal components may interact through a component such as the Episodic Buffer which allows a visual task to use both visual and verbal information.

The first chapter of the current doctoral thesis will detail these two multicomponent perspectives of the working memory architecture and will give details from alternative models associated with the working memory architecture. Models such as Kosslyn's Computational Model and Cowan's Embedded Processes Model will be discussed to give alternative explanations of the interpretation of the working memory architecture.

The second chapter will look at the methodologies which could potentially be used to assess such working memory models and will propose the two types of tasks that will be used during the development of the thesis. These types of task have been named as Quantitative Change Detection tasks and Qualitative Change Detection tasks. Finally, all subsequent chapters will discuss the experimental procedures which have been implemented to offer discussions regarding the most appropriate model of the working memory architecture associated with visual working memory tasks.

CHAPTER 1

Models of Working Memory

1.1 Chapter Overview

The aim of this thesis is to examine and clarify the nature of domain specific and domain general (or multicomponent types of) representations used within two tasks assumed to make demands upon Visuo-Spatial Working Memory (VSWM). As a beginning point for this thesis, a number of theoretical accounts of VSWM will be discussed. Initially those which have been modified in the last twenty years in order to highlight components which putatively afford the opportunity to bring semantics to a visual representation will be discussed. Later in the chapter, theoretical accounts whose associated methodologies will be extensively employed in the thesis, will be discussed which include two working memory capacity models of The Discrete Slot Model (Luck & Vogel, 1997) and The Shared Resource Model (Bays, Catalo & Husain, 2009).

The current chapter will discuss earlier models of VSWM (Baddeley & Hitch, 1974; Logie, 1995) to more contemporary accounts (Baddeley, 2012; Cowan 2005; Logie, 2011), highlighting the importance of the multicomponent versus domain specific processes within working memory.

1.2 Early accounts of working memory

1.3 Baddeley and Hitch (1974)

Baddeley and Hitch (1974), as seen in figure 1.1., created their three component working memory model, suggesting different components for the storage and processing of visual and verbal information. The three component model of memory was created which comprised of one master system namely the **Central Executive** and two slave systems named the **Phonological Loop** and the **Visuospatial Sketchpad**.

1.3.1 The Phonological Loop

The Phonological Loop is the component associated with short term memory of verbal information. Using maintenance and rehearsal mechanisms, verbal and auditory information could be stored. The early research on this working memory model was primarily focussed upon the Phonological Loop and how information was maintained within the Phonological Loop.

The Phonological Similarity Effect, researched by Baddeley (1990, 2012), suggested that participants find it difficult to distinguish between two words when they have very similar sounds. In the Phonological Loop, this makes retrieval difficult as it is hard to decide which word is needed at recall and which word is not.

The Word Length Effect (Baddeley, Thompson and Buchanan, 1975; Baddeley, 2012) was suggested to demonstrate how people find it easier to recall words with fewer syllables. Greater rehearsal techniques can take place in the phonological loop if fewer syllables are needed suggesting a time constraint upon the memory of such items. Baddeley (1997) proposed a time constrain upon the rehearsal of such items and indicated that items need to be rehearsed for approximately 2 seconds before retrieval is possible.

Articulatory Suppression (Baddeley, Lewis and Valler, 1984) is a technique that can be used during memory research where the participant has to speak out aloud, whether this be a single word or a phrase. Articulatory suppression was suggested to inhibit the rehearsal of verbal information within the Phonological Loop and was shown to be a useful technique during the investigations of the Phonological Loop (Baddeley, 2012).

Figure 1.1. Baddeley and Hitch (1974). Initial three component working memory model.

1.3.2 The Visuospatial Sketchpad

The Visuo-Spatial Sketchpad (VSSP) is the working memory component which was associated with the processing and memory of visual and spatial information. In the original 1974 model, Baddeley suggested that the VSSP was responsible for the storage and manipulation of visual material only. Baddeley (2012) later suggested that the VSSP actively rehearses both spatial and visual information, meaning that it can be difficult to define whether spatial or visual information is the most important type of information being stored accurately. This had been also suggested by research from Vergauwe, Barrouillet and Camos (2009) who had used both visual and spatial interference tasks to demonstrate the lack of two separate spatial and visual representational processes.

Baddeley (2012) suggested that binding of both spatial (location) and visual (e.g. colour) information occurs in the VSSP meaning that errors can occur when the wrong features are bound together. This was later investigated by Wheeler and Treisman (2002) and will be discussed throughout Chapter 2 (the next chapter) of the current doctoral thesis.

1.3.3 The Central Executive

The Central Executive is seen as the master component of Baddeley and Hitch (1974) working memory model. This master component was suggested to be responsible for the general purposes, such as the storage and retrieval of the information associated with each slave system. However, this component lacked research since Baddeley had developed his working memory model and this master system has been criticised for Baddeley's lack of clarification of what this component is designed to do. Baddeley (1996) initially suggested this to be a more general purpose component; however, the Central Executive was shown to have links to long term memory and was seen as the link between short-term and long-term memory integration. Baddeley (1990, 1996) initially suggested that the Central Executive was designed purely for processing abilities such as attentional control and the retrieval of items from memory, however, the lack of clarification of this still causes debates today (Logie, 2016).

1.3.4 Development of the Episodic Buffer – Baddeley (2000) and Logie (2011)

In 2000, questions were raised with regards to how the Phonological Loop and VSSP could store information that may not be domain specific.

The Phonological Loop was questioned about how articulatory suppression can affect the rehearsal of visually presented visual material. Baddeley, Lewis and Valler (1984) suggested that articulatory suppression should have a huge detrimental effect upon the Phonological Loop, stopping the rehearsal of the visual information. Research, here, demonstrated only a small effect so it was questioned as to how the digits are stored under articulatory suppression interference. Could they be stored both visually and verbally (see also St Clair-Thompson & Allen, 2013)? The introduction of the Episodic Buffer (Baddeley, 2000) gave rise to a solution for this issue. As the Episodic Buffer could integrate both visual and verbal information, this component can be used to explain the interaction between the visual and verbal material being used in the Phonological Loop. Could the material be passed through the Episodic buffer (or also stored in the Episodic Buffer) to allow the incorporation of both visual and verbal material?

The VSSP could be seen to assist the Phonological Loop, here; however, the Visuospatial Sketch pad is susceptible to effects of serial recall and is not suited to the type of recall suggested by articulatory suppression (Phillips and Christie, 1977). Baddeley (2000) therefore questioned whether the Phonological Loop and the VSSP could be connected in one way and suggested the creation of the Episodic Buffer.

Baddeley (2000) incorporated the use of the Episodic Buffer into his working memory model. The Episodic Buffer integrates all of visual, spatial and verbal information combining it into a meaningful sequence and then transfers this information to long term memory using the Central Executive. This means that the Episodic Buffer explicitly interfaces long term memory and semantic memory, providing the opportunity for semantics to be brought to the slave system representation. An example can be given from Baddeley, Vallar and Wilson (1987) who questioned as to how material in a meaningful sentence is stored in memory. Baddeley et al. (1987) suggested that people can use aspects of long term memory when they recall words that can be presented in a meaningful sentence. A problem arose as to how to explain this phenomenon. In his 2000 work, Baddeley used the Episodic Buffer as a link between long term memory and visual and verbal information, therefore this component is becoming a highly influential aspect of visual working memory models.

Baddeley (2000) suggested that the Episodic Buffer is controlled by the Central Executive and holds information for a limited time, in temporary storage, using multimodal representations. This means that visual and verbal information could be integrated within this process. The Episodic Buffer also incorporates the use of long term memory and allows an ‘episodic’ representation to be formed. The word ‘episodic’ comes from Tulving’s (1989) concept of episodic memory where short sequences of combined information are stored, using both slave systems and long term memory activation. This opens up the possibility of the representation to be embellished by the cognitive semantic system.

Logie (2011) also used the Episodic Buffer component in his elaboration of the original working memory model. This is discussed on page 9 showing the links between visual and verbal memory components.

1.4 Updated Views of Working Memory

1.4.1 Baddeley

In his (2012) work, Baddeley (as seen in figure 1.2. and figure 1.3.) distinguished the difference between the two states of information representation by expanding his ideas of the VSSP. It was suggested that objects have two dual states, 1) pre-categorical where the object is just made up of features and is not categorised and 2) object (categorical) where the object is categorised and is viewed and memorised as a whole object instead of just potential individual features. A key element of this account is the explicit re-iteration that information can access working memory directly from perceptual systems, the gateway account. This affords the possibility that domain specific representation can occur in working memory and contrasts with Logie (2011) where perceptual processing passes through LTM semantics filtering, and thus working memory content is more likely to be underpinned by LTM.

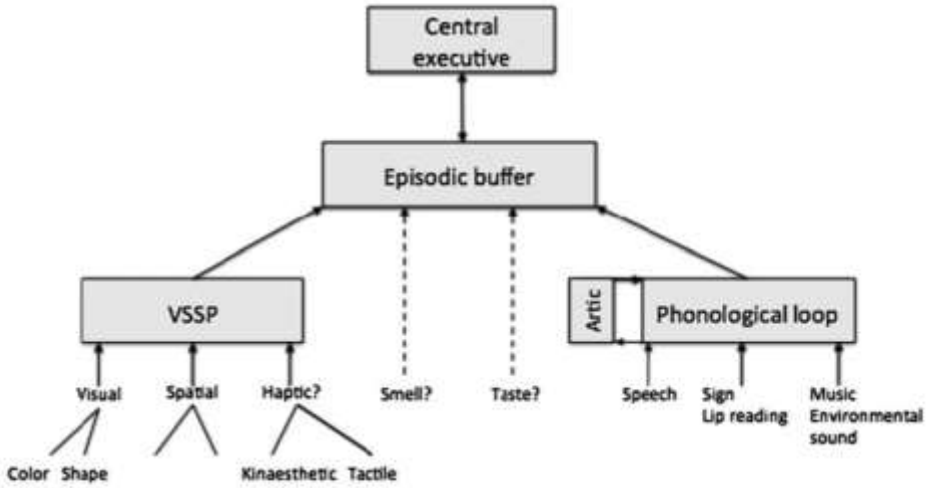


Figure 1.2. Baddeley (2012). An elaboration of Baddeley and Hitch (1974) in which perceptual information directly accesses the VSSP and Phonological Loop.

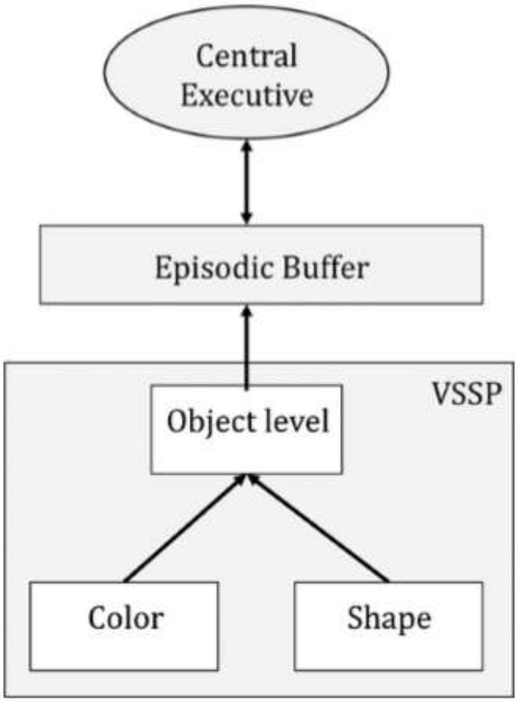


Figure 1.3. Baddeley, Allen and Hitch (2011). The VSSP dual representation account with pre-categorical and object based stages.

1.4.2 Logie’s Elaboration of the Visuospatial Sketchpad

A contrast to Baddeley and Hitch’s initial VSSP came from Logie (1995) who divided the VSSP into two sub-components. He suggested that, the Visual Cache stores information about visual information such as colour, and the Inner Scribe stores and rehearses information about spatial details, such as the location of an object.

The Inner Scribe supports the information in the Visual Cache and allows it to be rehearsed and ultimately transferred employed by the Central Executive component for ongoing or future use.

In later work, Logie (2011), as seen in figure 1.4., defined his working memory model as multicomponent where components interact with long-term memory underpinning and an Episodic Buffer like component. Knowledge about auditory and visual information are stored and are held together in what Logie (2011) named the Episodic Buffer. This concept (component) was taken from the work of Baddeley (2000) and adapted for the purposes of Logie’s working memory model. The Episodic Buffer collates all information into meaningful information ready for memory recollection. Logie (2011) suggested that all information, that will be stored in visual and spatial working memory, is derived through activation of the Episodic Buffer. However, unlike Baddeley (2012), Logie (2011) suggested that both visual and verbal information can be derived through this component as information is not filtered depending on what type. Because of this, Logie (2011) would presume that visual tasks, such as visual matrix tasks, can us verbal representation’s, contrasting the view of Baddeley (2012) who suggested that visual tasks can only use visual information.

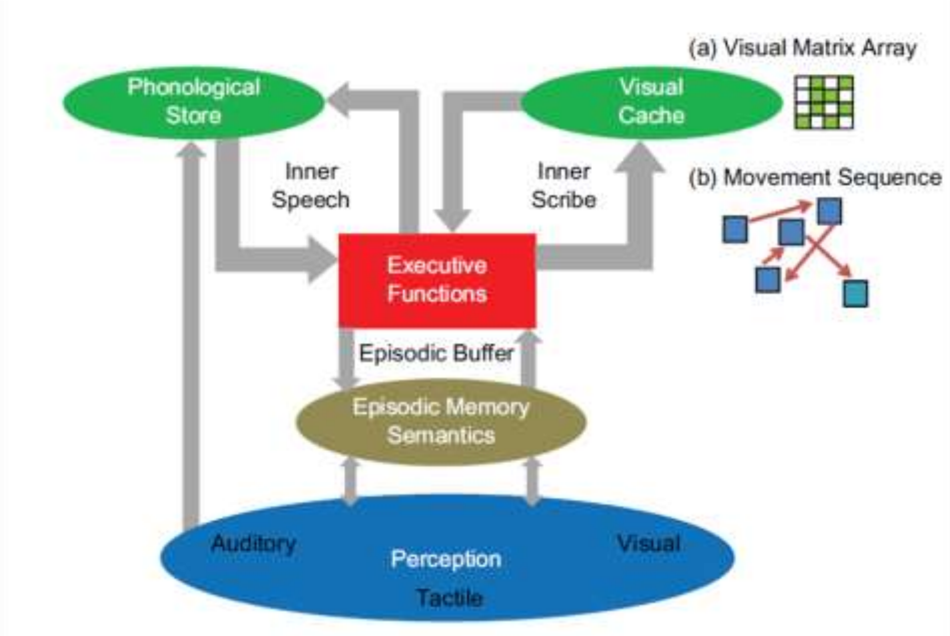


Figure 1.4. Multi-Component Model of Working Memory as suggested by Logie (2011).

These two models will be looked at in more detail during study 2 and study 4 of the current doctoral thesis. One of the aims of the doctoral thesis is to explore whether verbal semantics can be utilised in particular visual working memory protocol contexts.

To re-iterate, both the 1995 and 2011 revision of Logie's multi-component model of working memory differ from the original working memory model (Baddeley and Hitch, 1974) in one main way. As previously stated, Baddeley (2000) would suggest that information is directly inputted specifically to each working memory component, suggesting a gateway approach leading to perception of information directly accessing working memory. In contrast to this, Logie would suggest that perceptual information is initially processed using Long Term Memory; therefore, this account is not a gateway account as Baddeley's proposal was. The current model, from Logie, suggests that information is directed through memory on a more object level using the episodic buffer to combine different sources of information.

1.4.3 Cowan's View – Embedded Processes Model and the Emphasis Upon Attentional Resources in Working Memory

Cowan (1988) created a working memory model that was not seen as a multi-component model like those of Baddeley and Hitch (1974) or Logie (2011). There is no separation of visual and spatial processes within the model suggested by Cowan (1988), rather this model focussed upon how attentional components could link to long-term memory stores in order to underpin working memory. Instead of a specific short-term memory component, Cowan (1988) demonstrated that items in short-term memory might actually be items that are currently activated in long term memory.

Cowan (2000), as seen in Figure 1.5., suggested that long term memory can assist in the development of short term memory representations. In his updated model, it is suggested that there are two embedded components, the Scope of Attention (or the Focus of Attention) and also the Control of Attention. The Scope of Attention is the component which is always activated and this stimulates the activation of the Control of Attention when needed. The Scope of Attention is the component which links to long term memory, which is based on similar ideas to the Episodic Buffer created by Baddeley (2000, 2012).
Orme (2009) suggested that the allocation of attention within this model is controlled by two things. Firstly, changes in the environment allow us to direct attention towards the important information in the environment, and secondly, the allocation of attention can be voluntary (not automatic) and can be allocated through the Central Executive.

Cowan (2005) viewed working memory in terms of how a person can allocate their attention to different tasks. Two components were created namely the Control of Attention and the Scope of Attention. The Control of Attention differentiates differences in individuals who have high and low working memory spans and demonstrates how people can direct attention in different ways. For example, high span individuals can more effectively hold onto the goal of the primary task whilst performing a secondary task.

The Scope of Attention is concerned with the capacity of the Control of Attention and Cowan (2005) suggested approximately three to five chunks of information is present in the Focus of Attention.

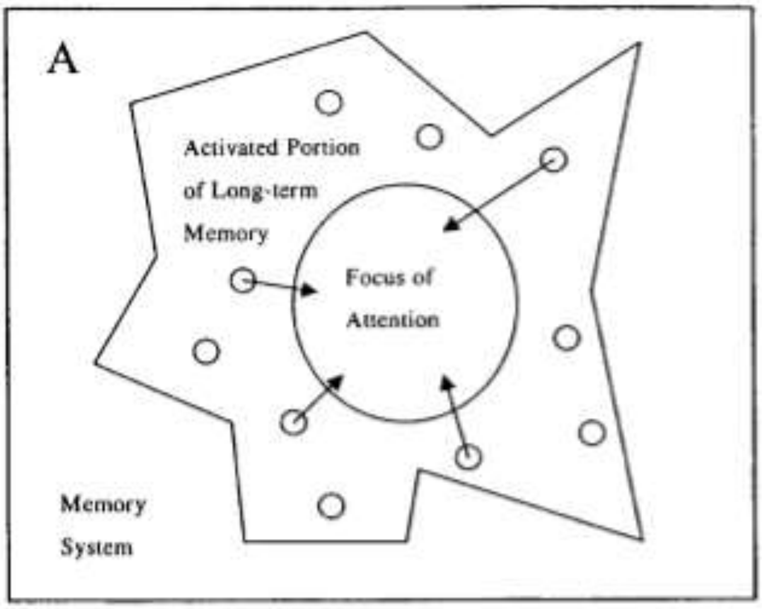


Figure 1.5. Cowan (2000). Attentional Focus Model of Working Memory. Originally suggested by Cowan (1988, 1995) as a nested framework.

Figure 1.5., above, details how information is directed to the Scope of Attention (circle) from the activated storage of long term memory. The Focus of Attention is seen as a limited capacity store, with approximately a storage level of 3-4 items/chunks of information. The small circles demonstrate any objects in the array, and the diagram demonstrates how these 4 items can enter the focus of attention after being activated in long term memory.

Cowan (2005) later suggested that allocation of attention aids working memory capacity, for example if an individual had good control of their attentional resources then working memory would be more accurate. This theoretical framework has been applied to both adults and children and suggests that children's working memory is less accurate as they are less focussed with their attentional resources and can pay attention to irrelevant items when this is not needed (Cowan et al., 2010).

1.4.4 Engle's Memory Model

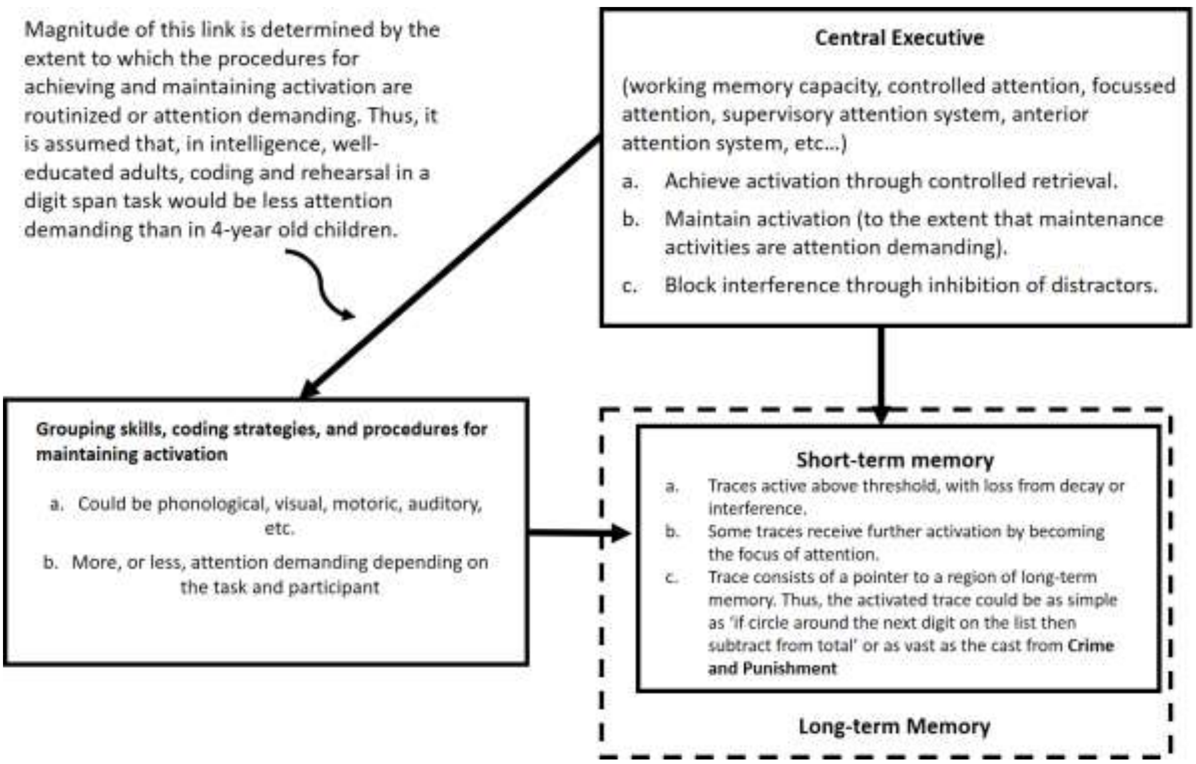


Figure 1.6. Relationship of various components of working memory. Taken from Engle, Tuholski, Laughlin and Conway (1999).

Engle's memory model (See figure 1.6.) also highlighted the importance of the Central Executive within working memory. This component was seen to be the source of controlled attention which was seen as the ability to store and maintain information during times of decay and interference. The Central Executive was suggested to block this interference from reaching the Short-Term Memory component. The Central Executive was suggested to activate Long Term Memory retrieval and enables Short Term Memory to use Long Term Memory traces.

This model highlights the differences between Short Term Memory and Working Memory. Short Term Memory was seen as the storage of information whereas Working Memory has the ability to maintain this information through controlled attention (as discussed above). Links between working memory and general fluid intelligence were proposed due to working memory being able to control attention. Similar processes are also needed during general fluid intelligence measures such as Cattell's Culture Fair Test (Cattell, 1973) and Raven's Progressive Matrices (Raven, Court & Raven, 1977).

Research from Unsworth and colleagues (Unsworth, Fukuda, Awh & Vogel, 2014; Unsworth & Spillers, 2010) also suggested that attentional control was an important factor in the links between working memory and intelligence. By extending the findings of Cowan et al. (2006), it was suggested that the links between working memory and intelligence measures can be mediated by individual differences in attentional control, capacity and secondary memory abilities. This highlights the importance of attentional processes within memory which have been previously proposed (Cowan et al., 2006; Engle et al., 1999).

1.4.5 Kosslyn's Computational Model

Kosslyn (2006), working memory within a visual imagery context, created an information processing account which offered a different perspective of a working memory process with the proposal of the Computational Model. A key element of this model was the Visual Buffer. Please see figure 1.7. for a visual representation of this. The Visual Buffer was a component which could temporarily maintain visual images, however it had the ability to become full (and overspill) when larger images were being stored. Kosslyn suggested that the Visual Buffer was able to store recently perceived information and also information which had been derived from long term memory representations. Once the Visual Buffer had stored the visual images, these images were then processed by the next components within the model. The next component was named as a Spatial Processing component which stored the spatial aspects of an image. Information within memory could also be sent to an Object Processing component which was used to store and rehearse the visual aspects of an image which had been encoded. Once the objects had been passed though the spatial or object processing components, an associate memory component was used in a similar way to Baddeley's Central Executive component. The aim of using this component was to decide if the initial inputted object was recognised in line with any Long Term Memory representations already stored. If the object had been recognised it was the processed through memory and recalled. If the object had not been recalled, then it was sent back to the Visual Buffer where the object information could be assessed again and amplified so that more details could be recognised. This process was repeated until as many objects as possible could be remembered. Similar to that of Baddeley (2011), Kosslyn's Computational Model directs information through the model on a perceptual model with limited or no influence from semantics until it reaches the Associative Memories Component. This could indicate a more domain specific approach to the working memory architecture (Quinn, 2008).

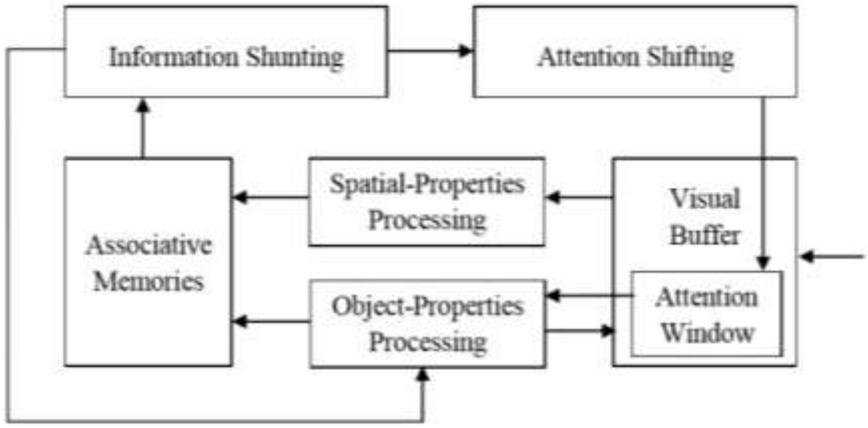


Figure 1.7. Kosslyn's Computational Model (Kosslyn, 2006, p136)

1.4.6 Pearson's Model

Pearson (2001) created a working memory model by integrating both models of Kosslyn (2006) and Logie (1995). This model, as with Logie's model, includes the slave systems of the Phonological Loop, Inner Scribe and the Visual Cache. However, the connections between the Inner Scribe and the Visual Cache were maintained by adding in Kosslyn's Visual Buffer component. See figure 1.8. for this model.

The Visual Buffer component within this model was used in a similar way to Kosslyn's visual buffer whereby the visual information could be directed from long term memory or more recent visual representations. However, one difference between this model and that of the original model by Logie (1995) was that the direction of the passage though memory was bi-directional. Information could be passed from the Visual Cache to the Visual Buffer and then to the Inner Scribe, but could also be passed back to the initial components. In this model, Pearson (2001) proposed the Visual Buffer to have a limited capacity where information could overflow into the Visual Cache and Inner Scribe. The Visual Buffer was also not capable of storing a series of representation and could only store one array at a time.

As with Kosslyn's associative memory component, the information that was difficult to recognise would be passed back to the Visual Buffer ready for re-organising.

Within this model, the Visual Cache is not perceived as a higher order recognition component and only has simple recognition abilities. The Inner Scribe is responsible for the spatial information and can either work independently or alongside the Visual Buffer component. The Central Executive is similar to that of Baddeley's (2000) model and is responsible for overseeing the slave systems. It ensures that the information is stored separately within the appropriate component and ensures that the information within the Visual Buffer is rehearsed just as the associate memory component does in Kosslyn's model. Kosslyn's Computational Model also has a similar structure to Baddeley, Allen and Hitch (2011) elaboration of the VSSP. Within Kosslyn's Computational Model, information is directed into Kosslyn's Visual Buffer and is then passed through the Object-Properties Processing component before any potential use of verbal semantics or long term memory. Similarly, Baddeley, Allen and Hitch (2011) have suggested that information is sent directly into the VSSP on a perceptual level, again with no influence of semantics or long term memory until after the information has been passed through the Episodic Buffer and into the Central Executive. Both Kosslyn's model and the updated view from Baddeley et al. (2011) suggest visual domain specific approaches to working memory with no interaction from long term memory stores until information has been directed through each model.

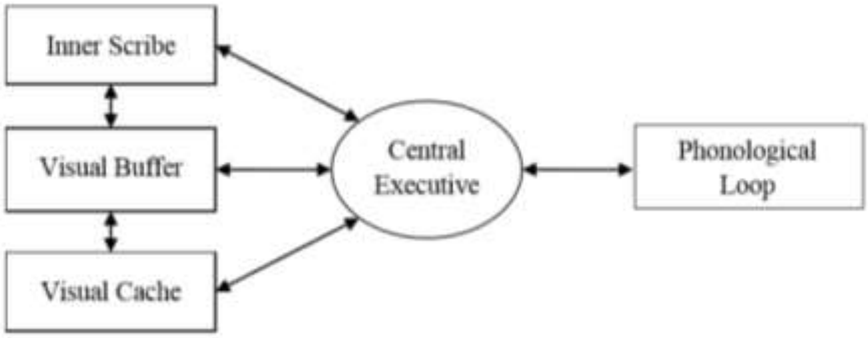


Figure 1.8. Pearson’s Visual Buffer Elaboration

1.5 Working Memory Models – Capacity Focussed

2 contrasting models of working memory capacity give details of the constraints acting upon how participants can memorise and recall items that have been stored in short-term visual memory. These two models will inform the methodological memory protocols employed for the duration of the thesis.

1.5.1 Discrete Slot Model

The Discrete Slot Model (Awh, Barton & Vogel, 2007; Luck & Vogel, 1997) conceptualised working memory capacity in terms of the number of items that can be stored. The model, as seen in Figure 1.9. suggests that working memory contains ‘slots’ which are filled when items are stored in working memory. Luck and Vogel (1997) give a capacity limit of 3-4 items, suggesting that when the capacity limit is reached, no further items can be stored and remembered. This is in line with the ‘magical number 4’ suggested by Cowan (2000). The Discrete Slot Model focuses upon large categorical changes (quantitative changes) in stimuli, for example changing a blue square to a red square. Luck and Vogel (1997) suggested that the Discrete Slot Model discusses information storage as whole or integrated object items instead of individual features. For example, a person could store a square and its orientation and colour in one slot instead of having a separate slot per feature. This essentially suggests that the maximum of 3-4 items could hold many features. If each object has four features, then as well as the four different items being held, sixteen features can also be held.

Rouder, Morey, Cowan, Zwilling, Morey and Pratte (2008) provided evidence for the slot model in suggesting that visual working memory does indeed have a fixed number of slots. In this experiment, array sizes 2, 5 and 8 were manipulated from Luck and Vogel's (1997) original paradigm. Receiver Operating Characteristics curves/lines were demonstrated to be at 1 for all set sizes, suggesting a linear decrease in performance of the visual memory task as set size increased. Researchers here suggested that the slot model could work just because of its simplicity although further research was suggested in an attempt to incorporate the potential encoding individual differences.

1.5.2 Shared Resource Model

The Shared Resource Model (Bays, Catalo & Husain, 2009, Bays and Husain, 2008) focused upon the resource trade-off between quantitative change detection task demands and qualitative change detection demands (small continuous changes). In stimuli, e.g. the finite or continuous coloured hue characteristics of a square. In this way, researchers can understand how the items are stored in memory, and in this case, the model suggests resource capacity may be best considered in the light of a trade-off between the number of items in an array and in terms of their resolution and precision of the items, therefore, not just simply how many items are stored.

Bays et al. (2009) suggested that one resource is shared equally amongst all items in a visual array meaning that each item can be stored. Within their research, array sizes of 1-6 were used and the precision of the items declined even between 1 and 2 items in the array. In comparison to the Discrete Slot Model, the Shared Resource Model would enable an array size of 6 to be stored successfully within memory. Precision would simply be less accurate than with a lower array size. As the Discrete Slot Model has a capacity limit of 4, an array size of 6 would simply not be encoded within memory due to the limited slots available for storage. As there was no fixed upper limit suggested, this indicates that all items in an array can be stored. Where more items are in the array to be store, less resource is allocated to each item due to it being distributed to more items in memory.

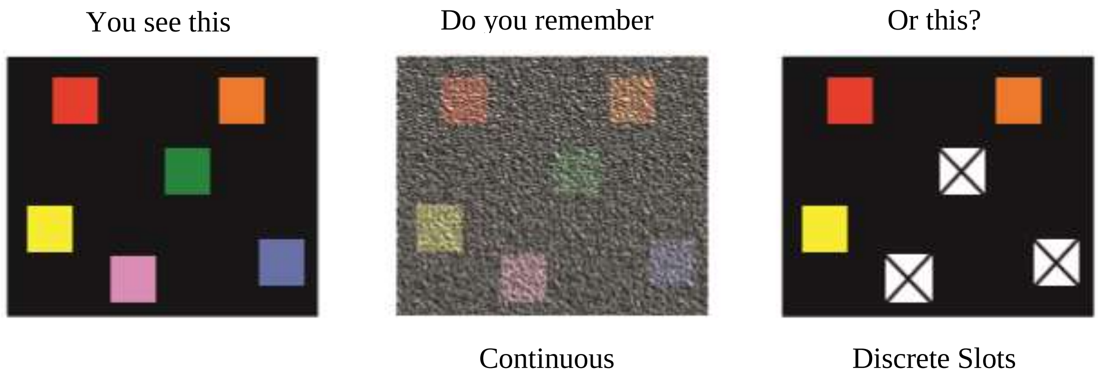


Figure 1.9. An example of the types of representations stored by the Shared Resource Model (centre) and Discrete Slot Model (right) taken from Luck and Vogel (2013).

Similarly, to Bays et al. (2009), Zhang and Luck (2008) created a model which used dynamically distributed resources. However, researches here combined both the idea of slots and a shared resource within the same model, naming this the ‘Slots+Resource’ model. The ‘Slots+Resource’ model suggested that people do store items within working memory slots, and as with the shared resource account, therefore are no upper limits. However, instead of the model simply counting the number of slots free, it was suggested that a resource is shared between each slot so that fine detailed slots could be created. Using a colour wheel methodology (to be critiqued in the following chapter) to show the precision within working memory capacity, it was suggested that the combination of slots and resources gave a more flexible account than the discrete slot model of Luck and Vogel (1997). However, although a limited amount of slots and a limited amount of resource was suggested, a concrete number was not applied to this model, creating its flexibility.

1.5.3 Contrasting View – Information Limited Model

Initial work from Brady and Alvarez (2011) suggested that the different objects in an array could influence the working memory capacity of an individual. However, this research used stimuli only created for their work (different coloured circles), therefore Brady and Alvarez continued their investigations using very familiar change detection paradigms.

In their more recent work, Brady and Alvarez (2015) discussed a model which suggests that there was no evidence of a fixed slot approach and suggested that instead of a fixed slot approach, working memory storage consisted of the storage of whole complex objects. In their research, an 'Information Limited Model' was used to explain working memory capacity. This Information Limited Model proposed that participants can only store 1-2 complex items in an array, unlike the previously proposed 3-4 items as suggested by Luck and Vogel (1997).

A series of three experiments were conducted, it aimed to replicate the results of Awh, Barton and Vogel (2007), Luck and Vogel (1997) and Alvarez and Cavanagh (2004) who all demonstrated the capacity limit of approximately 4 items. These included items with a range of level of complexity (Chinese characters, cubes, grey polygons and Snodgrass object). Brady and Alvarez (2015) demonstrated that participants could in fact only store one or two items within working memory and not the 4 items as previously suggested. These items, however, were not the simple square items as used by Luck and Vogel (1997). The items were very complex items such as the Chinese characters and cubes as used by Awh et al.

(2007) and Alvarez and Cavanagh (2004). Using both small changes in stimuli, known as within-category changes, and larger changes in stimuli, known as cross-category changes, it was shown that the cross-category changes were affected by the distribution of the other items in an array. The dispersion of the items in the arrays was positively correlated with the cross-category change performance. One reason for this correlation was suggested as the influence of the other items in the visual array. When clusters of different items were presented, improvements with cross-category changes were found. This was explained using a phrase known as 'spatial ensemble representation' and suggests that the storage of the clustered items allowed participants to store one key feature of a single items separately to the rest of the cluster. This key feature, for example, the darker shade of a cube, would mean that participants could easily recall the feature and therefore the object in the cross-category condition. As the within-category condition had no one feature which stood out to participants all items were stored as complex items making it more difficult to recall one individual items.

1.6 Relationship Between the Two Models (Number/Quantity versus Resolution/Quality).

Fukuda, Awh and Vogel (2010) looked at both the Discrete Slot model and Shared Resource models of working memory capacity to see if there were any distinct differences within the models. They reviewed the literature relating to each model, concluding that the models can overlap in the ways they describe working memory capacity limits. Fukuda et al. (2010) suggested that one way of comparing both models would be to look at the neural activity associated with each model as individual differences account for a large proportion of working memory task results. By looking at the neural components associated with set size and allocation of attention, (Contralateral Delay Activity, N2pc, P300 components), neural measures can provide electro-physical explanation to support or contradict the behavioural results from the working memory tasks.

Earlier work by Fukuda, Vogel, Mayr and Awh (2010) had looked at qualitative and qualitative stimuli in the context of a relationship with intelligence. This is one of the final aims of the current doctoral thesis, to look at qualitative and quantitative tasks in the same context, therefore more details will be provided in later chapters of the thesis.

Barton, Ester and Awh (2009) did suggest links between the two models in the way that they could account for working memory capacity. They conducted an experiment to investigate both the Discrete Slot and Shared Resource models. During experiment 1, participants were presented with arrays consisting of the stimuli used by Alvarez and Cavanagh (2004). These consisted of Chinese characters and cubes. Participants had to decide if a retrieval array was the 'same' or 'different' as a previously shown encoding array. The aim of this experiment was to examine the relationship between set size and resolution. Results concluded that within-category conditions are limited by resolution as this condition required the detection of small changes. Between category conditions would require the detection of large changes and could therefore be explained by the Discrete Slot model – one large change per slot. In experiments 2-5, researchers distinguished between the two working memory capacity models by keeping size constant, presenting objects sequentially and investigating the influence of complex objects. Researchers found distinct differences between the two models. Discrete Slot models explain how objects are rigidly allocated to memory whereas Shared Resource models explain how the resource is flexible and is not fixed per item. Shared Resource models are also concerned with the complexity of an object and the manner in which increased resource can be allocated to the more complex items, an account not provided for by the Discrete Slot model.

However, Barton, Ester and Awh (2009) did discover one possible link between the Discrete Slot model and the Shared Resource model. They suggested that working memory capacity could be defined by both number and the resolutions of the stored memories. The Discrete Slot model could account for the number of items that are stored (either simple or complex) and the Shared Resource model could account for the representations of each of these slots meaning that both models could be part of one larger resource model. They also proposed an alternative account suggesting that the number and resolution aspects of working memory capacity could act as two different aspects of working memory ability. This would mean that there would be no relationship between number and resolution, supporting findings from Awh, Barton and Vogel (2007). Researchers here found no correlations between the number and resolution of the stored items in working memory, supported later by Fukuda et al. (2010). Both Awh, Barton and Vogel (2007) and Barton, Ester and Awh (2009) suggested using converging methods in the form of neural measures (fMRI, ERP) to further investigate these issues.

1.7 Working Memory and Intelligence

Working memory capacity has been shown to have links to intelligence in both and adult and child populations (Cowan et al., 2011; Fukuda, Vogel, Mayr & Awh, 2010). Early work primarily focussed upon relating working memory capacity to intelligence using more language based measures. During more recent years, the orientation of this link has changed, and the research also emphasises the links between visual working memory capacity and intelligence.

Just and Carpenter (1992) conducted an early piece of research to link working memory and intelligence, concluding that larger working memory capacities suggest a greater intelligence.

In this piece of research, comprehension was seen to be the intelligence measure and was linked to working memory capacity through attention allocation. Just and Carpenter (1992) suggested a capacity theory of comprehension, however suggested that this was just a basic model as individual differences in lexical processing could occur.

In earlier work, Carpenter, Just and Shell (1990) had defined intelligence when using Ravens Progressive Matrices. Again, it was suggested that those who had a higher intelligence score also had a high memory capacity and suggested that those with lower capacity may have found decreased reasoning abilities and difficulty when completing matric patterns.

Kyllonen and Christal (1990) defined intelligence as reasoning ability and also questioned whether this was linked to working memory capacity. In four large studies, intelligence (reasoning ability) was shown to link to working memory capacity. Several reasoning tests, including mathematical, verbal and grammatical reasoning tasks were given to participants to assess all aspects of reasoning abilities. Working memory capacity tasks included digit span tasks and also mathematical capacity tasks that again were designed to test more than one aspect of working memory capacity. It was found that working memory capacity and grammatical reasoning were highly correlated, suggesting that high capacity participants had higher intelligence (and higher reasoning scores).

Fry and Hale (2000) emphasised the links between age, processing speed, working memory and intelligence with a review of the literature published before the year 2000. Reviews were conducted looking at age related working memory differences and also links to working memory capacity and intelligence were proposed with age related differences.

In more recent years, the research has focussed upon which aspects of working memory are the most effective predictors of intelligence (Mogle, Lovett, Stawski & Sliwinski, 2008).

Questions remain as to whether it is number of visually stored objects (Discrete Slot perspective with a Quantitative emphasis), or the resolution of the representations (Shared Resource perspective with a Qualitative emphais) that are more positively associated with intelligence (Fukuda et al., 2010).

Fukuda et al. (2010) identified that visual working memory was a predictor of intelligence. Using two different change detection methods, a task using small changes (qualitative task) and one using large changes (quantitative task), it was evidenced that the larger changes detected in the stimuli were more positively correlated to the higher scores on the intelligence measures. In contrast, Heyes et al. (2012) demonstrated the link between qualitative visual working memory stimuli and intelligence, in a child developmental context. Little research has been conducted on linking a quantitative visual working memory measure to intelligence, such as Luck and Vogel (1997) paradigm. This leaves an area for research open to interpretation. Although Fukuda et al. (2010) used a change detection paradigm consisting of lined shapes, the square coloured stimuli of Luck and Vogel's (1997) procedure has rarely been used in an attempt to find links with intelligence (Unsworth, Fukuda, Awh & Vogel, 2014) and also not in combination with qualitative task procedures.

As the more recent work will be discussed in the final chapters of the current doctoral thesis, this section has aimed to just give a brief overview of the literature associated with working memory capacity and intelligence measures.

The current PhD thesis will aim to add knowledge to the topic of working memory capacity and intelligence, and determine which working memory measure, quantitative or qualitative, can predict verbal a non-verbal intelligence in children. This thesis study will determine whether the number of stored objects or the resolution of the stored objects is the main visual working memory predictor of intelligence.

1.8 Chapter Summary

This chapter focussed on the models associated with working memory, starting with the original working memory models of Baddeley and Hitch (1974) and Logie (1995) before looking at the current models for working memory capacity. The main focus of the more specific models was on two contrasting models – the Discrete Slot model (Luck and Vogel, 1997) and the Shared Resource model (Bays et al., 2009).

The chapter has shown how both the Discrete Slot model and the Shared Resource model literature have developed since the creation of each model, including the beginnings of child investigations.

Relationships between the two models was also suggested to be a possibility; therefore, it gives the current thesis the aim of incorporating methods from both the Discrete Slot model and Shared Resource model into further studies.

Literature has demonstrated that working memory capacity investigations using both qualitative and quantitative methods are not limited to adults alone. In the final stages of this thesis (after the creation of qualitative and quantitative methods), working memory capacity in young children will be investigated using a combination of both methods. However, before investigating working memory capacity in children, appropriate quantitative and qualitative methods must be created and validated to ensure that the tasks are age appropriate. The next chapter will detail the chosen methodologies used for the first four studies of the current doctoral thesis, including reasons for the choice of a quantitative and qualitative change detection task.

CHAPTER 2

Thesis Methodologies, Aim and Rationales

2.1 Chapter Overview

Chapter 1 focussed on the theoretical perspectives which will underpin the current doctoral thesis. Discussions were made regarding the models associated with a domain specific approach to the working memory architecture of visual tasks and also the multicomponent approach which proposes the use of visual and verbal information during visual working memory paradigms. The importance of attentional resource models was also highlighted as part of the working memory models discussed. Two specific visual working memory capacity models were also detailed, forming the basis of the methodologies proposed for this thesis. The aim of the current chapter is to now distinguish the methods which could be used to assess the models of working memory representations (Baddeley, 2012; Logie, 2011). Several visuospatial working memory tasks will be discussed and issues will be raised which suggest reasons as to why current researchers have chosen specific methodologies. The final focus of this chapter will be to discuss the relevant change-detection protocols proposed for the reminder of the thesis, giving indications as to why these methods may be more suitable than others to investigate the representation use during visual working memory procedures.

2.2 Background

The use of both visual and spatial components in working memory was originally suggested by Baddeley and Hitch (1974). Since then, researchers have examined whether these components interact, potentially through and executive resource or an Episodic Buffer like component (Logie, 2011). Reviews of the past literature have provided evidence that visual and spatial components in working memory are separate systems. A variety of literature has suggested that these systems are two definitively separate systems, even when developing throughout childhood (Pickering, Gathercole, Hall & Lloyd, 2001). Pickering et al. (2001) had suggested the distinction between static and dynamic present types of visual memory tasks, proposing that developmental dissociations may be due to the differences in presentation type and not the differences in visual and spatial presentation. Below, details are given regarding the types of tasks that can be used to assess visual working memory and also spatial working memory.

2.2.1 The Corsi Blocks Task

The Corsi Blocks as seen in figure 2.1. task was developed to provide a non-verbal equivalent to the forward digit span (Milner, 1971). This task presents participants with nine blocks that are physically arranged in a random pattern. This participant is then shown a sequence of taps across the board and has to to reproduce this sequence by tapping the appropriate block in the same sequence.

It was originally thought that the Corsi Blocks task demanded spatial working memory processes only, due to the participant being asked to remember the spatial sequence of locations (Della Sala, Gray, Baddeley, Allamano & Wilson, 1999; Fischer, 2001), however, more recently it has been suggested that the Corsi Blocks Task may have forms of executive involvement as well as the originally proposed spatial involvement (Hamilton, Coates & Heffernan, 2003; Rudkin, Pearson & Logie, 2007; Thompson et al., 2006; Vandierendonck et al., 2004). Thompson et al. (2006) used the Corsi Blocks task in a clinical population to demonstrate that it may use some form of executive involvement. In a normal population, and within a population who had bi-polar disorder, it was shown that the Corsi Blocks task shared a large amount of variance with the executive tasks employed in the study. This indicates the potential recruitment of a Central Executive component within the task demands.

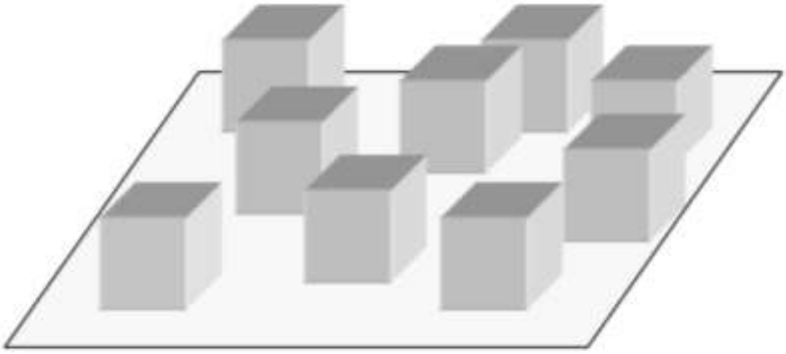


Figure 2.1. An example of the Corsi Blocks Task (Hamilton, Coates and Heffernan (2003). Participants are required to sequentially tap the blocks after being presented with a sequence by the researcher.

2.2.2 Visual Patterns Test/Matrix Patterns Task

The Visual Patterns Test (Della Sala et al., 1997, 1999) is derived from the visual matrix memory protocols of Phillips and colleagues (Phillips & Christie, 1977; Phillips, 1974). Please see figure 2.2. for an example of this task. In the recognition format, the participant has to determine whether a currently presented matrix pattern, made up of a novel configuration of black and white cells, is the same or different than one previously shown. More recent versions (VPT) of the task enable participants to recall the matrix pattern, cell by cell.

Logie and Pearson (1997) successfully used both the Visual Patterns Test recall and recognition versions in their investigation to show the separation of visual and spatial working memory components. The VPT was used alongside the Corsi Blocks Task in a developmental study and it was discovered that the systems which underpin the two separate tasks actually develop at different rates. This pattern of developmental fractionation was taken as evidence for discrete visual and spatial processes in working memory and appeared congruent with the constructs of the Visual Cache and Inner Scribe (Logie, 1995, 2011).

Memory for the matrix patterns was seen to be increasingly higher across the age ranges (5-6, 8-9 and 11-12 years) suggesting that the development of the visual working memory component (Visual Cache) was at a greater rate than the suggested spatial component (Inner Scribe), however Hamilton (2013) has proposed that this pattern of developmental fractionation may disappear when the VPT and Corsi Blocks scores are standardised. As with the Corsi Blocks task, there has been increasing evidence to suggest that executive resources may contribute to VPT task performance (Brown & Wesley, 2013; Hamilton et al., 2003; Rudkin et al., 2007).

The duration of the encoding image within a memory task is one that needs to be considered with caution. Originally, Phillips (1974) suggested that an encoding time of 100 milliseconds was enough to encode the information successfully without the use of any verbal strategies or forgetting. This meant that participants had the time to encode the visual information without attempting to use any form of verbal representation. Similarly, with the use of a change detection protocol, Luck and Vogel (1997) contrasted both 100 milliseconds and 500 millisecond encoding intervals in their experiments, proposing no difference in recall accuracy of the retrieval items. These researchers also suggested that a 500 milliseconds encoding duration may not be sufficiently long enough to use any verbal coding or strategy use. However, studies investigating effects of visual working memory capacity have suggested that proactive interference effects can occur when participants are being presented with a series of trials (Hartshone, 2008). Lin and Luck (2012) on the other hand, used a five item colour change detection task and demonstrated no such effects with regards to a 100 millisecond maintenance interval.

In this context, the VPT was originally thought to be a purely visual memory task, in terms of having a visual format of representation. However, subsequent research has employed sustainability longer encoding times which have afforded opportunities for executive resources and attentional control processes to semantically elaborate the visual pattern, despite their novel configuration (Brown & Wesley, 2013; Logie & Pearson, 1997; Rudkin et al., 2007). Rudkin et al. had used a 2 second encoding interval and proposed that this duration was enough to allow the use of executive attentional resources and long term memory to occur. Hartshone (2008) also proposed proactive interference effects with regards to colour change detection task, encouraging the current thesis to use a shorter encoding duration (of 500 milliseconds) to eliminate the possibility of proactive interference effects.

The contribution of executive resources was evident in the research findings of Rudkin et al. (2007, study 1). The contribution of executive attentional resources to the VTP task performance has been extensively researched by Brown and colleagues (Brown, Forbes & McConnell, 2006; Brown & Wesley, 2013).

In the recent work, Brown and Wesley (2013) provided strong evidence that the VPT representation within working memory may not be purely visual as first thought. The work of Brown et al. (2006) identified that participants could verbally label matrix patterns and consequently they developed high and low verbal coding of the VPT stimuli. The High Coding stimulus pattern set would mean that participants could more readily create a verbal label for the pattern and the Low Coding category meant that participants had more difficulty in creating a rich form of verbal label. The high verbalisable sets of images lead to higher VPT task performance. Brown and Wesley (2013) made use of an executively demanding secondary task, random interval tapping, in order to remove the performance advantage for the high verbal VPT.

Results from the study demonstrated that the executive attentional interference removed the advantage of the high verbal coding category. The findings of Brown and Wesley (2013) suggested that this proposed visual working memory task may indeed use verbal semantics and recruit executive resources as part of the maintenance process.

These conclusions can be accommodated within the Multi-Component Models of working memory from Baddeley (1974, 2000, 2012) and Logie (2011) who identified the functional interaction of each component with the use of an Episodic Buffer and executive resources. However, it should be noted that in these models, the VPT representation has been conventionally identified more with the VSSP and Visual Cache respectively, rather than a representation that emerges from slave and executive resource interaction.

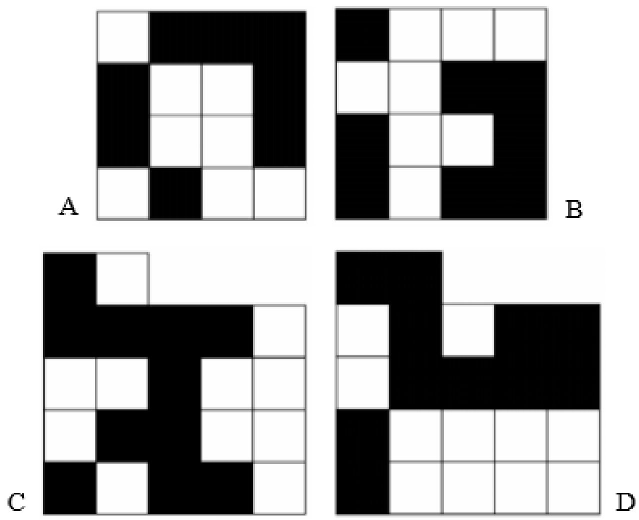


Figure 2.2. An example of the Visual Patters Test used by Brown and Wesley (2013) A and B represent patterns from level 8. C and D represent patterns from level 11. The memory test method is the recall version rather than the recognition version.

2.2.3 Issues with Corsi Blocks and VPT

Work by Rudkin et al. (2007), Hamilton et al. (2003) and Vergauwe et al. (2009) suggested that the Corsi Blocks and VPT may not be as domain specific as first though and one of the aims of the current thesis is to look at this with regards to a visual change detection protocol.

Rudkin et al. (2007) demonstrated that a random number generation task had more detrimental effects on the Corsi Blocks Task than it did with the VPT. This suggests that the Corsi Blocks Task may have greater executive involvement. As the current doctoral thesis is aiming to look at visual working memory, it can be said that the Corsi Blocks Task is not appropriate in this case to use. Firstly, the task is not visual specific, as the VPT could be. The potential contribution of executive resources could mean that several working memory components are used during this task meaning it would be difficult to define which component is specifically related to each part of the task.

A similar conclusion is also implied with the VPT. As Brown and Wesley (2013) have shown, an executive resource may also be at use here, meaning again it would be difficult to define which elements of the task are using visual representations and which elements are not. Therefore, the VPT will also not be used during the current doctoral thesis as this may now not be seen as a purely visual working memory demanding task.

One other issue that lies with the two previously discussed tasks is the way in which each task is presented. The Corsi Blocks task is presented sequentially, where the tapping of block items is necessarily sequential presentation. Rudkin et al. (2007) demonstrated that sequentially presented working memory tasks have more executive interference costs than simultaneous ones. In their research, both the Corsi Blocks Task and the VPT were used and compared based upon their presentation types. The interference effects of random digit generation were more greatly present when the information was sequentially displayed, indicating that there could potentially be a form of executive resource use when information is displayed sequentially. The presentation of the stimulus leads to an issue of whether the tasks could alternatively be labelled as simultaneous versus sequential visuospatial working memory tasks (Pickering et al., 2001). Thus, patterns of developmental fractionation originally interpreted as visual/spatial process differentiation could actually be simultaneous/sequential process differentiation. See Darling, Della Sala and Logie (2009) for consideration of this issue. As a result of these issues, the current doctoral thesis will not be using either the Corsi Blocks Task or the Visual Patterns Test as the primary visual working memory research tools in order to avoid any issues regarding presentation type format or clear recruitment of executive resource use. Instead, a different type of visual memory task will be used – a change detection task such as those used by Luck and Vogel (1997) and Thompson et al. (2003).

2.2.4 Quantitative Visuospatial Memory Tasks

To overcome the influence or potential use of executive attentional resources within a working memory task, it may be possible to use a different task protocol. In this type of task, known as a change detection task, participants are shown a brief display of an encoding image, followed by a retention interval which is displayed before a final retrieval or proble image is presented. The retrieval or probe image can display either a change or no change of which has to be identified by the participant. Change detection tasks have conventionally been used to investigate working memory capacity in terms of information load (Alvarez and Cavanagh, 2004), looking at visual working memory capacity in terms of information load (Alvarez & Cavanagh, 2004; Phillips & Christie, 1977), looking at the working memory of faces (Scolari, Vogel and Awh, 2008) and have also been used in developmental contexts to investigate working memory capacity in young children (Cowan et al., 2006; Riggs, McTaggart, Simpson and Freeman, 2006; see also Hamilton et al., 2013).

An early change detection paradigm, constructed by Luck and Vogel (1997), as seen in figure 2.3., has been widely used throughout the visual working memory literature. Luck and Vogel

(1997) used their initial paradigm with college students, however, since then the paradigm has also been successfully used with children (Cowan et al., 2005)

In their 1997 work, Luck and Vogel showed participants arrays of 1, 2, 3, 4, 8 or 12 coloured squares. A retrieval array was shown, for 2000 milliseconds, consisting of the same number of squares, and participants had to decide if there was a change (or not) in the cued square in each retrieval array. Initially the encoding arrays were displayed for 100 milliseconds with a 900 millisecond maintenance interval; however, a comparison was made to the encoding display of 500 milliseconds to see if the longer encoding time encouraged any encoding differences. The authors identified that there were no differences in performance of the change detection task when participants were exposed to both the 100 millisecond and 500 millisecond encoding array conditions. The encoding time of 500 milliseconds has subsequently been used throughout the change detection literature (e.g. Alvarez and Cavanagh, 2004; Luck and Vogel, 1997; Riggs et al., 2006; Scolari et al., 2008).

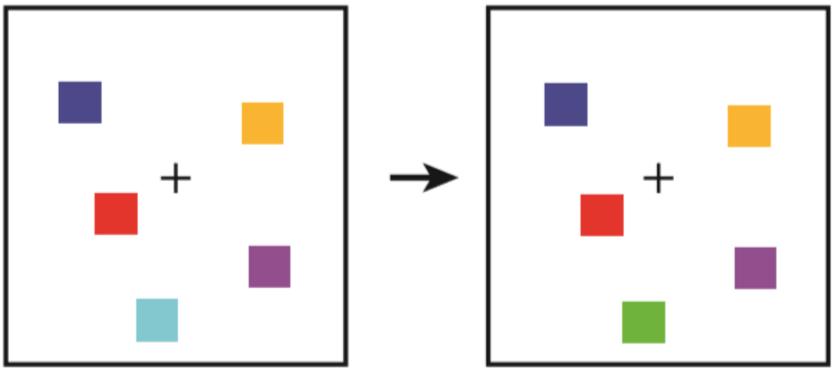


Figure 2.3. An example of a change detection paradigm (Luck and Vogel, 2013). This was successfully used by Luck and Vogel (1997) and also Riggs et al. (2006). Participants have to decide if the second array is the same or different as the first array.

In a more recent review, Luck and Vogel (2013) defined visual working memory tasks as *‘First, to qualify as VWM, it is not sufficient that the information was acquired through the visual modality; the representation of the information must be visual in nature. If the observer stores a verbal or amodal conceptual representation of the sensory input, we no longer consider it to be a visual memory’* (Luck and Vogel, 2013, page 2).

Here, it was suggested that visual working memory tasks should use visual representations only and should have no verbal influences such as those that have been shown with the VPT (Brown et al., 2006; Brown & Wesley, 2013).

To control for verbal influences in their original work, Luck and Vogel (1997) used a verbal load task to eliminate any use of verbal representations. Participants were asked to hold two digits in their mind and recall them at the end of each trial, essentially preventing the use of verbal material during the visual working memory task. This inhibited any verbal influences, such as those seen in the VPT and the Corsi Blocks Task (Thompson et al., 2006).

As a result of this ‘visual only’ perspective, the current doctoral thesis will aim to use a change detection paradigm as one of the aims of the thesis is to specifically look at visual working memory tasks. The Corsi Blocks Task and the Visual Patterns Test will not be used due to the increasing research regarding the use of potential executive attentional resources during these tasks (Brown and Wesley, 2013; Hamilton et al., 2003; Rudkin et al., 2007).

Although current researchers have suggested change detection protocols to be an appropriate source of visual working memory assessment, there are criticisms of these tasks. As previously discussed, the possibility of proactive interference within the task is one which cannot be identified fully. Hartshorne (2008) used a 1000 millisecond encoding interval in their work, presenting effects of proactive interference and potential semantic representation use with this extended encoding duration. Phillips and Christie (1997) also used a 1 second encoding interval, demonstrating that this encoding time was long enough to enable to use of long term memory. However, Lin and Luck (2012) used an alternative encoding duration of 100 milliseconds to show no proactive interference effects within their colour change detection paradigm. This shorter maintenance interval was show to have no interference effects with different shapes, circles and orientated bars, concluding that the shorter maintenance interval was more appropriate to use in a working memory paradigm. As Luck and Vogel (1997) had suggested no difference between the 100 millisecond and 500 millisecond maintenance interval in their work, the current thesis will employ a 500 millisecond maintenance interval as this has been used in both adult (Fukuda et al., 2010) and child contexts (Riggs et al., 2006).

Another point to consider is the Hierarchical Encoding perspective offered from Brady and Alvarez (2011, 2015) which suggests that there are organisational and long term memory influences during full arrays probe contexts. Brady and Alvarez suggested that when an encoding array of multiple probes is presented, the participants unconsciously compute 'Ensemble Statistics' with a mean amount of the size or colour of all items in an array as well as the initial information about each individual items in the array. Brady and Alvarez suggested that this second form of representation is susceptible to long term memory organisational influences. Because of this, there could be influences of long term memory within change detection tasks where items are recalled as full arrays and not individual stimuli as previously proposed by Luck and Vogel (1997). This is one point to consider with regards to visual change detection tasks as it could potentially mean that arrays larger than 1 may still be susceptible to long term memory influences even when the task has been designed to eliminate the use of verbal coding.

Other criticisms of the change detection protocol retrieval contexts have been made. Wheeler and Treisman (2002) conducted investigations using Luck and Vogel's change detection task, giving details of the use of both single and full retrieval probes. Wheler and Treisman (2002) suggested that the use of a single retrieval probe would eliminate any need to bind information within memory, such as colour and location; therefore, memory errors would be reduced. Multiple retrieval probes may increase the task demands and may potentially need greater attentional control of the stimuli presented. Brady and Alvarez (2011) contrasted this, suggesting that a full array can be seen as an advantage to the participant. In their investigation, a full array was presented to participants and researchers demonstrated that participants used the full array to form the representation of the item to be recalled. The issue of single versus multiple retrieval probes is one of which will be investigated during the next chapter of the current thesis. Before implementing any change detection task, researchers will pilot the change detection task using a single and multiple retrieval probes to discover if any differences in performance are present.

In summary, the change detection tasks discussed above, have all been used in contexts to assess ‘large’ or quite discrete changes in visual memory and consequently are known as quantitative memory tasks. For example, Luck and Vogel (1997) could have changed a red square to a blue square. These tasks relate to the previously discussed Discrete Slot Model (Luck and Vogel, 1997) in chapter 1, which focus upon the number aspect of visual working memory capacity. In more recent research (e.g. Bae and Flombaum, 2013; Dean, Dewhurst & Whittaker, 2008; Dent, 2010; Thompson et al., 2006), small or continuous changes in visual memory have been assessed using a different protocol of change detection tasks. These tasks may be labelled as qualitative tasks as they do not measure capacity of visual working memory, but the fidelity, resolution or quality of the maintained visual representation. The current doctoral thesis will aim to look at both quantitative and qualitative representations in visual working memory. These tasks are associated with the Shared Resource Model (Bays et al., 2009) which is concerned with looking at the fine grained representations within working memory instead of the amount of objects that can be stored.

2.2.5 Qualitative Visuospatial Memory Tasks

In contrast to the large changes assessed by quantitative change detection tasks, qualitative tasks assess small changes. These changes can range from a finite colour of a square (Zhang and Luck, 2008) to the size change of a shape (Thompson et al., 2006). The small changes in visual memory are related to the resolution of the stored items (and not just the number that large changes are) and one way of measuring the precision of how accurately the image is maintained is to vary the change in visual attribute by employing increasingly smaller size changes (Thompson et al., 2006).

Heyes et al. (2012) investigated precision in working memory using a developmental example. A qualitative memory task was created which asked participants to look at the orientation of up to 3 bars. In one condition, only one bar was shown and in a second condition, three sequential different coloured bars were shown. Participants were asked to reproduce the orientation of the specified bar by using a dial to rotate a probe bar until it matched the orientation of the memorised bar. The degree of error was measured and calculated as the precision of memory for each bar, for example, how accurate the participants were at detecting the small rotation changes of bars 1, 2 and 3 separately.

Results did demonstrate an improvement in precision with age, however, one issue with this task was the demonstration of a recency effect. Participants detected the most recent item more accurately. In Heyes et al. (2012) the detection of the rotation change in the third coloured bar was shown to be more accurate compared to the first and second sequentially presented bar. Phillips and Christie (1977) and Allen, Baddeley and Hitch (2014) both differentiate the underlying maintenance processes of the recency item from the earlier items in a sequential presentation of visual patterns. Allen *et al.*, suggest a major role of executive attention in the maintenance of these pre-recency items, whilst Phillips and Christie suggest that visual long term memory may underlie the maintenance of the pre-recency items. As a result of these considerations, sequential change detection tasks will not be used for the current doctoral thesis.

Another type of qualitative visual memory task, called the Size Just Noticeable Differences Task (Phillips and Hamilton, 2001) was created to avoid such sequential effects. In this paradigm, participants are presented with one square offset to the left of the centre of a screen. A second square is presented, offset to the right of the screen, and participants have to decide if the second square is the same or different size as the previous one. As all items are presented not in a sequence, this overcomes any problems with sequential effects and can reflect visual memory more accurately. Phillips and Hamilton (2001) gave details of the size JND and demonstrated that size changes could range from a 50% change to a 5% change depending upon the visual perceptual competencies of the participants.

Thompson et al. (2006) used the size JND in a more clinical context to assess the working memory of individuals who have bi-polar disorder. Both the Corsi Blocks Task and the Visual Patterns Test were also used during this investigation to look at any potential use of executive resources in these tasks. It was concluded that the size JND was potentially a measure of visual memory, relatively free of executive resource demand, in contrast to the Corsi Blocks Task and the VPT procedures. Because of this, the current PhD will incorporate the use of the size JND task into the qualitative visual working memory task protocol.

Bae and Flombaum (2013) incorporated the rationale of the size JND into one of their visual working memory tasks in order to investigate precision in visual working memory. A change detection task, similar to that of Luck and Vogel (1997) was created, however as well as a study looking at colour memory; a study looking at size memory was also created. In this task, participants had to view an encoding array of either 1 or 2 shapes. After a retention interval was displayed, a retrieval stimulus was presented and participants had to decide if this probe shape was bigger or smaller than the corresponding one previously shown. The work of Bae and Flombaum (2013) was created to look at potential correspondence errors within working memory. The current study will address this issue by using two different shapes in each encoding array to eliminate any cost of a correspondence error. The change detection task of Bae and Flombaum (2013) will be incorporated with the size changes of the Size Just Noticeable Differences Task (Phillips and Hamilton, 2001) to ensure that there is a wide range of size changes. These size changes will range from 5 to 25% increases and decreases in size, similar to that of Bae and Flombaum (2013).

2.3 Methods for Investigating the Differentiation of Modality Specific from Modality General Representations

2.3.1 The Use of Interference

Based upon the work of Vergauwe et al. (2009) in attempting to differentiate visual and spatial interference impact, and that of Allen et al. (2014), the current doctoral thesis will employ a dual task methodology to investigate the type of representation use of the quantitative and qualitative change detection tasks. The visuospatial Bar Fit task will be taken from the work of Vergauwe et al. (2009) to assess the impact of visuospatial interference on both types of change detection tasks. During this task, participants have to respond has to respond to a series of three items as whether a bar could pass through a gap between two dots. Vergauwe et al. (2009) proposed that this task requires the use of visuospatial attentional resources as it was demonstrated that the Bar Fit task could interfere with both visual and spatial working memory protocols.

As one of the main aims of the current thesis is to look at the domain specific versus the multicomponent nature of two change detection tasks, a verbal attentional interference protocol will be added to look at the use of the verbal components of the working memory architecture. Lépine, Bernardin and Barrouillet (2005) introduced a verbal interference protocol known as a Verbal Parity Task. Within this task, participants are verbally presented with a series of three numbers and after each number is presented, a keyboard response is made deciding whether the number is odd or even in nature. Lépine et al. (2005) proposed that this task specifically used the Phonological Loop component within the working memory architecture, however it was also suggested that this task could be detrimental to memory due to the ability to encourage participants to divide attentional control between a primary and secondary task.

The use of a dual task methodology can assist in providing evidence towards either a multicomponent or domain approach to the attentional/semantic representation use of these tasks. If the Bar Fit Task only causes interference effects then a domain specific approach can be adopted (Baddeley, 2012). If verbal interference effects are present then this can raise question with regards to the multicomponent approaches to visual working memory (Logie, 2011).

2.3.2 The Use of ERP

An alternative methodology to differentiate the modality specific versus modality general architecture is based upon the work of Riby and Orme (2013). Riby and Orme investigated the working memory architecture of a variation of the Visual Patterns Test by using electrophysiological recordings to do so. Three specifically chosen ERP components were used in the experiment. The N400 ERP component was chosen as this had been shown to have a heightened activation if the use of semantics were present during the encoding of faces (Eimer, 2000) and non-visual word stimuli (Kutas and Federmeier, 2011; Kiefer, 2002). The N200 ERP component was used as a marker of early visual processing and it was proposed that this component was activated when more complex visual stimuli was presented (Berti, Geissler, Lachmann and Mecklinger, 2000). Morgan, Jackson, Klein, Mohr, Shapiro and Linden (2010) had proposed that the N200 was colour visual specific, prompting the current researchers to also use this ERP component. Finally, as a marker of attentional control, the P300 was used. Riby and Orme (2013) suggested that this component would be activated during times when greater attentional control was needed throughout a task. Similar suggestions have been made from Lavric, Forstmeier and Rippon (2000) who demonstrated a heightened P300 with a task requiring several visual and verbal cognitive functions.

The use of the visual specific N200 and the verbal specific N400 can give current researchers an indication of the domain specific or multicomponent nature of the quantitative and qualitative change detection tasks. If both the N400 and N200 are activated during each task then these can be discussed in terms of multicomponent approaches (Logie, 1995, 2011). If only the N200 is activated, then support can be provided for the more domain specific approaches to visual working memory architecture of change detection protocols (Baddeley, 2000, 2012).

2.3.3 The Relationship with Verbal and Non-verbal Ability

The work of Fukuda et al. (2010) proposed strong links between quantitative measures of working memory capacity and intelligence (also known as ability or reasoning ability), with the ability for this measure to predict non-verbal intelligence. In their investigation, two change detection tasks were presented to participants with one using quantitative array changes and a second using qualitative array changes. Fukuda et al. (2010) indicated a two factor model for the prediction of intelligence, with the quantitative measure of working memory capacity providing a significant contributor to the intelligence measure scores, unlike the qualitative measure.

In contrast to this, a developmental investigation from Heyes et al. (2012) suggested strong links between qualitative measures of working memory capacity and intelligence in children aged 7-13 years. As previously discussed during this chapter, a qualitative measure of a bar orientation task was implemented to look at the precision of the children's memory. These precision measures were shown to share a large amount of variance with the children's' Full Scale IQ scores, indicating that qualitative visual working capacity measures can also have a strong link to intelligence as well as the quantitative measures previously proposed by Fukuda et al. (2010).

In discussing the overall aim of the current thesis, to look at whether domain specific representations or multicomponent representations are being used by the change detection tasks, a piece of research from Shah and Miyake (1996) is one to discuss here. Shah and Miyake (1996) investigated the domain specificity of both spatial and verbal working memory resources in relation to spatial thinking tasks and language processing tasks. Experiment 1 carried out correlations between all measures finding that spatial arrow spans had strong correlations with spatial ability tasks. In contrast, reading span measures had strong correlations to verbal SAT scores, proposing a more domain specific approach to verbal and spatial working memory measures. In their second experiment, similar results were found to that of experiment 1 even when the task type was taken into consideration (processing or storage). Regressions were carried out between the simple and complex processing version of the verbal and spatial tasks to discover if the language processing abilities and spatial thinking abilities could be predicted. Conclusions were made suggesting that tasks which can have high demands of verbal processing and storage predict language processing. Similarly, tasks that can have high demands on spatial processing and storage can have the ability to predict performance on complex spatial thinking tasks.

As with Shah and Miyake (1996), the current thesis will aim to look at the domain specific versus domain specific question with regards to the quantitative and qualitative change detection protocols. If these tasks can only predict non-verbal intelligence measures, then a domain specific nature of these tasks can be suggested in a similar way to that of Shah and Miyake (1996; see also Shipstead & Yonehiro, 2016).

To assess the nature of the representation used within the quantitative and qualitative change detection task in the current thesis (domain specific versus multicomponent), a developmental investigation will be conducted to discover whether each change detection task has the ability to predict verbal and non-verbal intelligence. As the current thesis aims to focus not only on non-verbal intelligence measures, Wechsler's Abbreviated Scale of Intelligence (2011) will be used. This measure has separate sub-scales for both verbal and non-verbal intelligence measures, meaning that two separate scores will be given for the verbal and non-verbal intelligence tasks. Fukuda et al. (2010) had used Ravens Advanced Progressive Matrices (1939) as the intelligence measure. The current doctoral thesis could not use this measure as Ravens Advanced Progressive Matrices does not offer a complementary form of verbal reasoning ability.

2.4 Methodological Summary

This chapter has given details regarding conventionally and more recently used visuospatial working memory task protocols. Two main issues were raised with reference to the presentation type (sequential versus simultaneous) and the potential use of an executive attention or controlled attentional resources in visuospatial working memory tasks. Consequently, it was decided that quantitative and qualitative change detection tasks will be used in an attempt to eliminate these issues and to assist with the development of a visual working memory thesis. The next chapter will detail and pilot the first visual memory task created for the purposes of this doctoral thesis, Luck and Vogel’s (1997) change detection task which includes the discussion of a putative problem associated with conventional change detection task protocols – a potential issue arising from the nature of the retrieval context.

2.5 Thesis Aims

The overall aim of the current doctoral thesis is to investigate the functional working memory architecture of two visual change detection tasks to discover if the representations used are visual specific in nature or whether a multicomponent approach can be adopted instead to discuss the functional working memory architecture. Baddeley (2012) had suggested that visual tasks use visual information only with the discussion of a perceptually driven gateway account; however, Logie (2011) contrasted this with suggestions about a visual matrix task (VPT). Logie (2011) had used the component of an Episodic Buffer to discuss how a visual task may use visual and verbal forms of representations, making the functional working memory architecture multicomponent in nature.

Two visual change detection tasks, a quantitative and a qualitative task, will be used in the current thesis to discover if verbal representation use can be used within these tasks, similar to the suggestions made about the Visual Patterns Test.

The two change detection tasks will be created using contrasting visual working memory capacity models. The first change detection task, using Quantitative stimuli is based upon the Discrete Slot model of capacity (Luck and Vogel, 1997). This model defines working memory capacity in terms of the number of items stored and can be assessed using large changes in visual arrays, such as the changes of coloured squares. The Qualitative change detection task will be created using the perspectives of the Shared Resource Model (Bays et al., 2009). This model takes into consideration the resolution of the stored representations, gives no upper limit of the amount of objects that can be stored, and is assessed using small changes in visual arrays such as the precise size change of a shape.

The aim of the first two studies of current doctoral thesis is to pilot the two working memory paradigms which will underpin the remaining experimental procedures during the course of the doctoral thesis. A quantitative change detection task will be utilised, which was initially created by Luck and Vogel (1997). In this task, colour changes in visual arrays are detected using a 'change/no change' paradigm where participants have to decide if a probe square array the same or different colour as one previously shown.

A qualitative change detection task will be created using a combination of the protocols of Bae and Flombaum (2013) and Phillips and Hamilton (2001). Researchers here looked at the small changes in visual arrays, with both Phillips and Hamilton (2001) and Bae and Flombaum (2013) using shape size changes. In these tasks, small changes in size may be varied, ranging from a 5% change to a 25% change.

Once the two visual memory paradigms have been chosen and created, the next aim will be to use interference paradigms to look at the types of representations used in each task. Luck and Vogel (2013) recently suggested that visual tasks should only use visual representations; however, other experimental investigations (Brown and Wesley, 2013) contrast this and suggest that visual tasks can use verbal representations as well. Within the interference chapters of the doctoral thesis, two contrasting working memory models will be discussed. Baddeley (2012), developing the original 1974 model, suggests a visual domain specific approach with a gateway perceptual entry of information into the VSSP. Logie (2011), on the other hand, suggests a more multicomponent approach to visual working memory architecture with the possibility of LTM semantics informing the perceptual information representation within the Visual Cache. The main aim of using interference procedures will be to discover if these two change detection protocols are seen as domain specific as originally suggested Baddeley (2012) and Luck and Vogel (1997) or whether multicomponent approaches to the working memory architecture could be a more appropriate consideration instead.

Before applying the quantitative and qualitative visual memory tasks to an ecological context of visual working memory and general reasoning ability in children, one more experimental investigation will be conducted and this will be to record electrophysiological data. The aim of the electrophysiological investigation will be to try and support the interference studies in relation to the types of representations being used. The N400 ERP component and the N200 ERP component will be used in this case. The N400 is a verbal semantically related component and can be used to suggest the use of verbal information. To contrast this, the visual specific N200 can be used to indicate early visual processing. Riby and Orme (2013) demonstrated a heightened activation of the N400 component when participants completed a visual matrix task, suggesting the use of an executive resource or Episodic Buffer component within the working memory architecture. The current thesis aims to incorporate similar protocols with the qualitative and quantitative change detection task as a heightened N400 would suggest the two tasks use some form of verbal semantics (or an Episodic Buffer) in the two change detection tasks. At present, there are no electrophysiological studies which use two different types of change detection task in the context of investigating the N400. The current PhD will provide novel findings from this research.

The fourth, aim of the current doctoral thesis is to apply the given knowledge of both visual change detection tasks to a developmental context and link these results to verbal and non-verbal intelligence in children aged 7-13. Luck and Vogel (1997) and Riggs, McTaggart, Simpson and Freeman (2006) primarily focussed upon the application of quantitative tasks in a developmental setting whereas Heyes et al. (2012) focussed upon the application of qualitative tasks with this setting. Fukuda, Vogel, Mayr and Awh (2010) used a qualitative and quantitative adapted visual memory task in an adult context to demonstrate the link between these two types of task and measures of intelligence. The current thesis will aim to do this using young child sample, to discover if these suggested relationships with intelligence (from Fukuda et al., 2010) can be found in children as well as the suggested adult population. At present, there are no investigations which have used a quantitative and qualitative visual working memory tasks simultaneously in a developmental context.

This final investigation will aim to incorporate use both the quantitative and qualitative change detection task and then link these task performances with potential measures of intelligence. In this case, the Wechsler Abbreviated Scale of Intelligence will be used as this task has a version which can be used with children aged 7-13 years. As the overall aim of the current thesis is to discuss whether the both change detection tasks are multicomponent (Logie, 2011) or domain specific (Baddeley, 2012) in their working memory architecture, the developmental investigation hopes to provide data towards answering this question by using both verbal and non-verbal intelligence measures. If the change detection tasks can predict both verbal and non-verbal intelligence, then these can be seen as more multicomponent in nature.

CHAPTER 3

Evaluating the Luck and Vogel Change Detection Procedure

3.1 Chapter Overview

Chapter 2 gave details of the potential methods which could be used for the current doctoral thesis, concluding that visual change detection tasks would be used to assess visual working memory. The present chapter discusses this method and details Experiment 1 of the doctoral thesis which aims to pilot the chosen change detection memory task. This chapter will also investigate an issue regarding the retrieval context within visual working memory, proposed in chapter 2, which questions whether single or multiple retrieval probes are the most appropriate to use during the execution of a change detection memory task in the presence of an encoded hierarchical organisational representation. Background literature will be discussed, detailing reasons behind the creation of the current experimental procedures. Results will be presented in relation to findings of the previous retrieval context literature research which also questions the retrieval probe use in visual working memory. Issues associated with the potential presence of Long Term Memory support for the visual representations within the change detection protocol will also be considered.

3.2 Background

Large categorical changes, also known as quantitative changes, in visual memory capacity can be assessed using change detection paradigms, similar to those of Luck and Vogel (1997). These were discussed in Chapter 2 of the current thesis. Luck and Vogel researched these quantitative changes in visual arrays, identifying the Discrete Slot Model (1997) as a model for defining visual working memory capacity. In chapter 1, this model was identified; it proposed a simple ‘slot’ approach to visual working memory storage, having a limit of approximately 3-4 items. Change detection paradigms have been employed to investigate the

Discrete Slot Model and have been used in numerous pieces of literature (e.g. Luck & Vogel, 1997; Scolari, Vogel & Awh, 2008; Brown & Brockmole, 2010); however, there remains an issue with regards to the potential of organisation of the array elements and the subsequent implications for the type of retrieval context within these paradigms. Are single or multiple stimulus retrieval probes the most appropriate to use in a visual change detection task given the potential for hierarchical organisation (Brady & Alvarez, 2011, 2015)? The current chapter aims to address this issue by using a methodology which includes both single and multiple retrieval probe types.

3.2.1 Retrieval Issue Question

Brady and Alvarez (2011, 2015) investigated visual working memory capacity, suggesting that multiple objects in a retrieval/probe array could influence the recall of an object in working memory. In their research, participants were asked to remember the size of 1 red, blue or green circle, out of an array of 7 different sized circles. The circles were of differing sizes; however, each type of colour was presented with the same diameter. Results were in line with the predictions made, demonstrating that participants would pay attention to the full array, being biased towards the size of a retrieval circle that was the same colour as in the encoding arrays. For example, if a participant was shown a blue circle with 1cm diameter at retrieval but had blue circles with a 3cm diameter at encoding; participants would recall the single blue circle with a 3cm diameter. Brady and Alvarez (2011) suggested a configuration issue here meaning that other objects in the array could influence how accurate participants were in recalling the retrieval object. In the research presented by Brady and Alvarez (2011), participants used the full array to aid recall and therefore paid attention to all objects in the array. As all circles were not the same size, errors in the recall of each array were shown as participants mis-judged the size of the circles based upon the presence of other stimuli within the array.

Luck and Vogel (1997), on the other hand, argued that participants store objects as independent units therefore there are no influences from other array items as Brady and Alvarez (2011) had suggested. In their earlier work, Luck and Vogel (1997) had proposed that people do not pay attention to the full array when encoding the image. In a series of smaller investigations, it was demonstrated that people store individual items within memory, whether these items be single featured items or multiple featured items. In this research, it was suggested that people could store simple shapes such as squares and also more complex shapes such as squares with different coloured borders. Due to the fact that each item fills a slot within working memory, there is no influence of the remaining objects in the array, meaning that multiple probes retrieval contexts do not have any advantage over single probes. This will underpin one of the hypotheses as predictions will be made regarding the differences between the multiple and single retrieval probes.

Jiang, Olson and Chun (2000) investigated the organisation of material in visual short term memory, in particular the influence of spatial information in arrays, such as the location of an object. Researchers, here, suggested that the configuration of each array can affect how accurately a series of objects is remembered. For example, participants need to pay attention to spatial aspects of an item, such as location, so that they can combine both visual and spatial information in memory to aid recall. Jiang et al. (2000) suggested that arrays are stored based on global configuration, meaning that arrays are stored as a whole where people consider both spatial and visual aspects at the same time (see also Brady & Alvarez, 2015).

In a series of eight smaller experiments, the basic paradigm from Luck and Vogel (1997) was used; however, this was manipulated to incorporate conditions where the spatial configuration was manipulated. Overall results demonstrated that configuration within a stimulus element is an important aspect of visual working memory storage, for example, being able to combine colour and location in memory to assist with recall. This process is known as binding and is discussed in detail by Allen, Baddeley and Hitch (2011). Jiang et al. (2000) highlighted the importance and advantage of using multiple probes here. In a single probe condition, there is no combination of colour to location at retrieval, meaning it may be more difficult to identify which colour was present at the time of encoding. For the purposes of the current investigation, an advantage of this full retrieval context would mean that this context is not appropriate for the measurement of visual working memory capacity. As researchers are aiming to avoid the use of spatial cues with those presented in full arrays, any spatial advantage of the full arrays would mean that this retrieval context would not be used.

A key piece of literature from Wheeler and Treisman (2002) also raised questions with regards to the retrieval context of the Luck and Vogel (1997) change-detection task protocol. Researchers, here, investigated retrieval arrays in terms of single versus multiple objects in these arrays. It was found that multiple object probe arrays can cause problems such as mis-binding in working memory, contradicting the research from Brady and Alvarez (2011). As part of their initial investigation, Wheeler and Treisman (2002) also used the paradigm created by Luck and Vogel (1997) and it was suggested that when participants are presented with several objects; it can be difficult to bind the correct object’s colour and location from their own capacity store, causing binding errors in memory recall. Wheeler and Treisman (2002) suggested using single object retrieval arrays as a way of reducing this error, however, it was not investigated as to which type of single retrieval probe should be used, for example a single central or single peripheral retrieval probe. Such a hypothesis would suggest an advantage in performance within the single probe context and could give current researchers an indication of whether a single retrieval context is the most appropriate to use within the remainder of the doctoral thesis.

Prior change detection research has successfully employed a single probe retrieval context. Jackson, Wu, Linden and Raymond (2009) used singe retrieval probes successfully when investigating the visual working memory capacity for faces. Researchers here presented between one and four faces in the encoding array, however, as with Wheeler and Treisman (2002), only one face was presented at retrieval. This provides further support for the fact that a single retrieval probe may be the most appropriate the use, as single probes have been used in both shape and face contexts within visual memory capacity research.

3.3 Rationale for Study 1

The previous research, above, provides a question about the retrieval context which needs to be addressed. The aim of the initial studies in the thesis is to identify whether performance in the single probe retrieval context differs from the conventional Luck and Vogel (1997) full array protocol.

Participants will be exposed three types of retrieval arrays. The first condition will consist of a full retrieval array with one cued square (similar to Luck and Vogel, 1997). The second condition will consist of a single central square and the third condition will consist of a single peripheral square in any of the eight possible locations. Wheeler and Treisman (2002) had concluded that single retrieval probes were the most appropriate to use, however they did not specify whether a central location or a peripheral location was the most appropriate, therefore this will also be investigated. Array sizes of 1, 2, 4, 6 and 8 will be used during this pilot investigation as these had been used by Wheeler and Tresiman (2002) and Luck and Vogel (1997). It was decided not to use the array size of 12 which had been used by Luck and Vogel (1997) as this size was too demanding on memory and did not reach a 60% performance level required for the current doctoral investigations. Results from the current study will also inform the remainder of the doctoral thesis colour change detection protocols. Findings will inform the development of the appropriate quantitative change detection task retrieval arrays in which to incorporate attentional interference paradigms into. In addition, the findings will inform the colour change detection protocol for the Event Related Potential research and the pertinence of change detection performance for verbal and nonverbal ability in children.

3.4 Calculating K-Scores

As a way of calculating the working memory capacity of each retrieval context, K-scores will be created using the formula from Cowan et al. (2005, appendix H). There are two versions of the formula with one taking into consideration the full array retrieval context $k = N*(H+CR-1)/CR$ and the other taking into consideration the single retrieval conditions of the peripheral and central probes $k = N*(H+CR-1)$. The formula from Cowan et al. (2005) takes into consideration both hit rates (H), the amount of correct change detections, and also the correct rejection rates (CR) which are the amount of correct responses that are rejected (e.g. amount of non-changes detected). Array size (N) that the K-score is concerned with is also an important factor in these equations as the array size will influence the amount of items held in memory.

Researchers such as Shipstead et al. (2014) have also used variations of this K score formula to estimate working memory capacity within their investigations. Please see appendix H for further details regarding the formula used.

3.5 Predictions

1) Participants will perform more accurately in the single central retrieval array condition, with this condition having the highest average score across all array sizes.

2) Array size 8 (in all conditions) will be the most difficult array size to complete; therefore, participants will have poorer performance on this block of trials.
3) Array sizes 1 and 2 will have performance levels of nearly 100%, similar to those of Luck and Vogel (1997).
4) The K scores for the single retrieval condition will higher than those of the full array with a cue and the single peripheral condition, indicating that this condition is more accurately performance with a larger capacity score.

3.6 Method

3.6.1 Design

A 3 x 5 repeated measures design was used as all participants took part in each experimental condition. Factor 1 was the retrieval context, consisting of three levels – single central probe, single peripheral probe and full array with cue. Factor 2 was the array size containing 5 levels of array sizes 1, 2, 4, 6 and 8.

3.6.2 Participants

A total of 15 Undergraduate Psychology Students (11 females and 4 males, with a mean age of 21 and a standard deviation of 2.05) received four course credit points for their participation in the experiment. All participants were recruited from a North East University.

3.6.3 Materials

There was only one quantitative change detection task used during this experiment, created using E-Prime 2.0.

3.6.3.1 Quantitative Change Detection Task (all conditions)

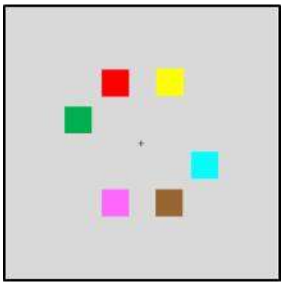
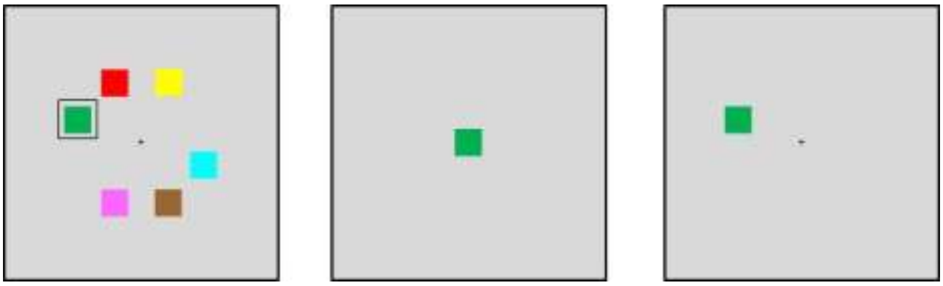


Figure 3.1. An example of an encoding array containing six coloured squares.



A B C

Figure 3.2. An example of each type of retrieval array. A) full array with a cue, B) single central probe, C) single peripheral location probe.

A practice task was created for all participants to complete before the main experimental phase began. This practice task contained arrays from all five array sizes and all three retrieval conditions, with three trials for each separate retrieval condition and array size.

The experimental change detection task contained five randomly ordered experimental blocks with each block containing one array size. The array sizes were 1, 2, 4, 6 and 8 coloured squares. In each experimental block 60 trials were shown, giving a total of 300 trials in the full experiment. The 60 trials in each experimental block consisted of: 20 retrieval arrays that were created using a full array (of the chosen array size) with one cued square; 20 retrieval arrays which presented only one square in a central location and the final 20 trials contained only one square at a randomly chosen peripheral location. After each group of 20 trials, a three-minute rest break was given to participants; however, participants could carry on without a rest break by pressing the 'SPACE' bar on the keyboard. Please see Figures 3.1. and 3.2. for examples of the encoding and retrieval arrays.

3.6.3.2 Trial Procedure

Each trial consisted of the presentation of an encoding array of either 1, 2, 4, 6 or 8 squares, presented for 500 milliseconds on a computer screen (Luck and Vogel, 1997). A fixation was presented at first for 1000ms. A maintenance array was then shown and this contained one central cross, presented for 900 milliseconds. Finally, a retrieval array was presented for 3000 milliseconds or until the participant pressed the corresponding key on the keyboard.

Participants had to decide if the highlighted square in the retrieval array was the same or different colour as to one in the encoding (memory) array. Participants had to press 'z' on the keyboard when the same array colour had been presented, and the 'm' on the keyboard when a different colour had been presented. In the example below, shown in Figure 3.3., a 'Z' response would be required.

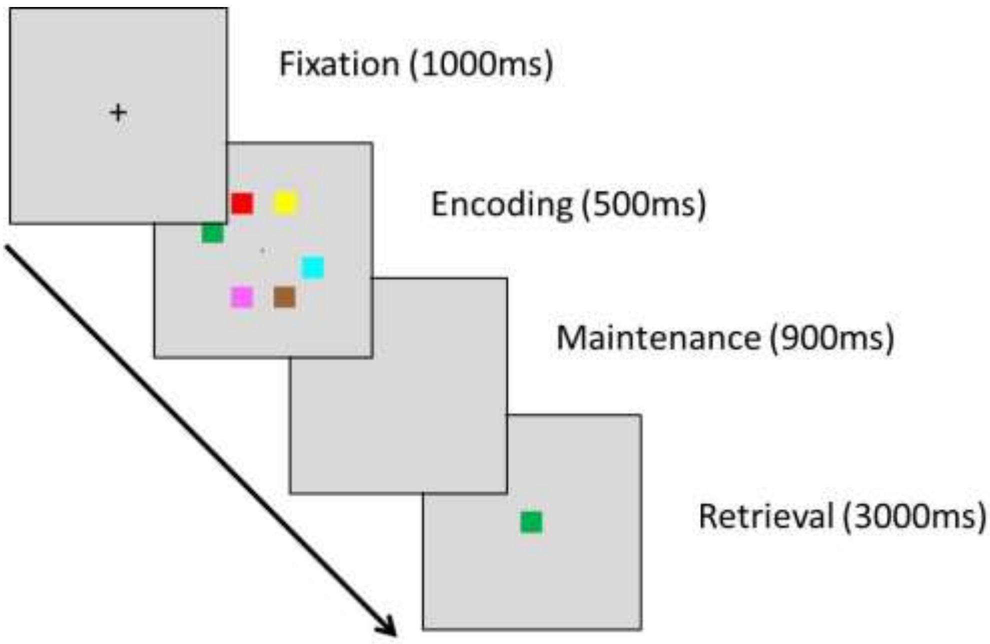


Figure 3.3. An example of one trial of the quantitative change detection task. This trial sequence was repeated for all retrieval conditions shown in figure 3.2.

3.6.4 Procedure

The current investigation was ethically approved by the University Health and Life Sciences Ethics Committee. The total testing session lasted one hour. The task was fully explained to participants before the testing phase began, an information sheet was read and a consent form was signed by participants. Please see Appendix A for an example of the task instruction sheet to participants.

Participants were asked to work through the task themselves, pressing the appropriate keys on the keyboard when prompted. Before the task began, instructions were displayed on the screen and participants completed a series of practice trials. Participants then had to press the 'SPACE' bar to continue to the experimental phase of the task. Before each new testing block began, the array size was displayed on the screen so that participants knew the array size being presented next. This prepared the participant for the upcoming array size to reduce any confusion. When rest breaks were given during the task, participants were instructed to press the 'SPACE' bar on the keyboard to continue with the task. The researcher did not prompt the participant to do so.

When testing completed, participants were notified on screen and were asked to wait for further instructions from the researcher. At this point testing had finished and participants were thanked and were fully debriefed, including a reminder of the right to withdraw.

3.7 Results

3.7.1 Scoring

The first part of the analysis used a simple scoring procedure, total correct score, where participants were awarded 1 point for a correct response and 0 for an incorrect response. This enabled a qualitative comparison with the original Luck and Vogel (1997) pattern of results. The total score for the whole task had a maximum of 300. The maximum score for each array size could total 60 and the maximum score for each array size within each of the three retrieval conditions could be 20.

For the purposes of this analysis, researchers were primarily concerned with the differences between each retrieval array type (full with cue, single central or single location) and also the differences between the five array sizes (1, 2, 4, 6 and 8 squares). This will be followed by more appropriate K score analyses. Once the negative K scores had been disregarded from the analysis, only 11 participants were included in the K analysis instead of the original 15.

Post Hoc Analyses

Where post hoc analyses were needed for a main effect given from an ANOVA, the Bonferonni function within the ANOVA SPSS analysis was used which automatically adjusts the alpha level accordingly. When following up an interaction effect, this Bonferroni function was not used and instead, paired smaples t-tests were conducted with the appropriately adjusted p values for each correction (for example, alpha/number of hypotheses tested).

3.7.2 Overall Raw Data ANOVA results

A 3 (retrieval condition) x 5 (array size) repeated measures ANOVA was conducted on the raw data to look at any potential effects of array size and interference condition. This was an initial analysis using all 15 participants' raw data.

Table 3.1. Means and standard deviations of the raw scores in each condition.

	Array 8	Array 6	Array 4	Array 2	Array 1
Full Array with Cue	12.8(2.24)	14.73(2.09)	16.93(2.15)	19.26(.88)	19.33(.82)
Single Central	13.06(1.48)	14.26(2.49)	16.46(2.47)	19.20(.77)	19.20(1.08)
Single Peripheral	12.33(3.13)	14.13(2.47)	17.26(1.87)	19.06(.96)	19.13(1.06)

Table Notes:

There was no significant main effect of the probe/retrieval condition on recall accuracy, *$F(2,13) = .535$ $p = .598$, partial $\eta^2 = .076$*, suggesting that participants did not perform more accurately in any one condition. However, a significant main effect of array size, *$F(4,11) = 59.39$, $p < .001$., partial $\eta^2 = .956$* was found. Bonferroni corrections found that array size 8 was less accurately performed (M = 38.20, SD = 6.85) than all other array sizes. Please see Table 3.1.for details of the means and standard deviations of each array size.

There was no significant interaction between array size and condition, *F(8,7) = .428, p = .871, partial* η^2 *= .329.*

3.7.3 Performance Levels

In order to make a qualitative comparison with the original Luck and Vogel (1997) findings, performance levels were calculated for each array size by totalling each participants score for all three conditions in each array size. This was then divided by the total by the highest possible score of 300.

Figure 3.5. demonstrates that the performance levels from the current study are in line with those of Luck and Vogel (1997) in Figure 3.4. In particular, the performance levels of array size 1 (M = 96.10, SD = 2.96) and array size 2 (M = 96.00, SD = 2.61) demonstrate the most similarity with potential ceiling effects.

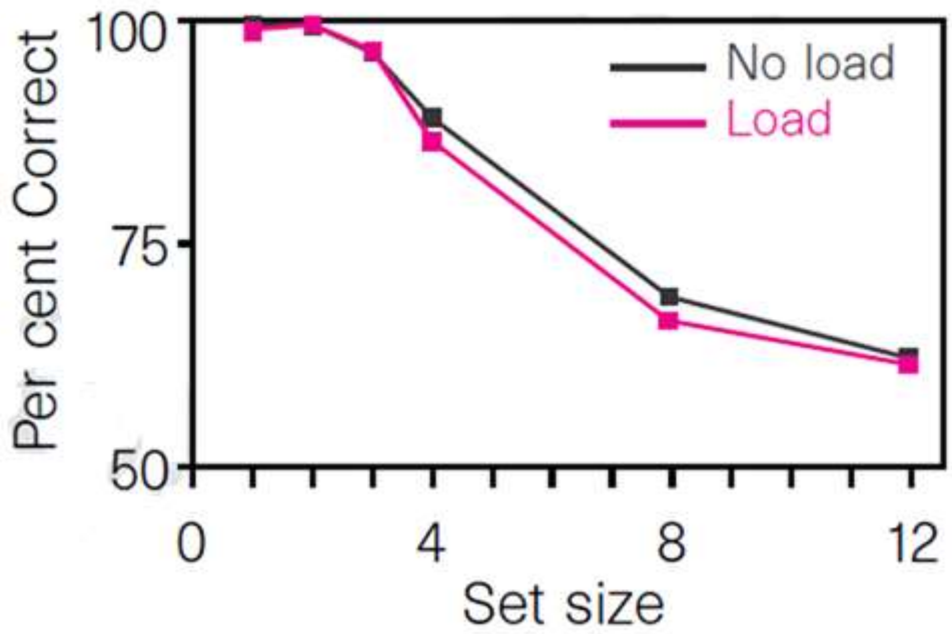


Figure 3.4. Graph showing performance levels of the Luck and Vogel (1997) experimental investigation.

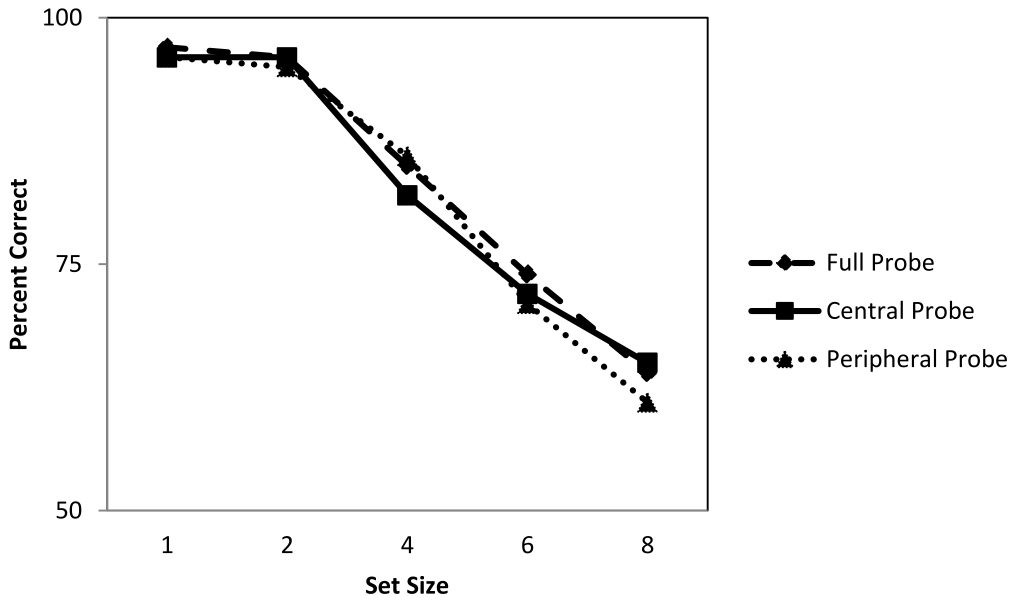


Figure 3.5. Graph showing performance levels of the current pilot investigation.

3.7.4 K-Scores

For this section of the analysis, 4 participants' data were excluded as the k-scores were calculated to be negative scores. As working memory capacity cannot have a negative score, the data was not used.

3.7.5 K-Score ANOVAs

Table 3.2. Means and standard deviations of the K-scores in each condition.

	Array 8	Array 6	Array 4	Array 2	Array 1
Full Array with Cue	4.41(2.07)	4.65(1.28)	3.62(.45)	1.92(.10)	1(0)
Single Central	2.54(1.22)	3.32(1.05)	2.94(.82)	1.87(.18)	.96(.05)
Single Peripheral	2.25(2.28)	2.83(1.04)	3.12(.58)	1.81(.20)	.91(.12)

Table Notes:

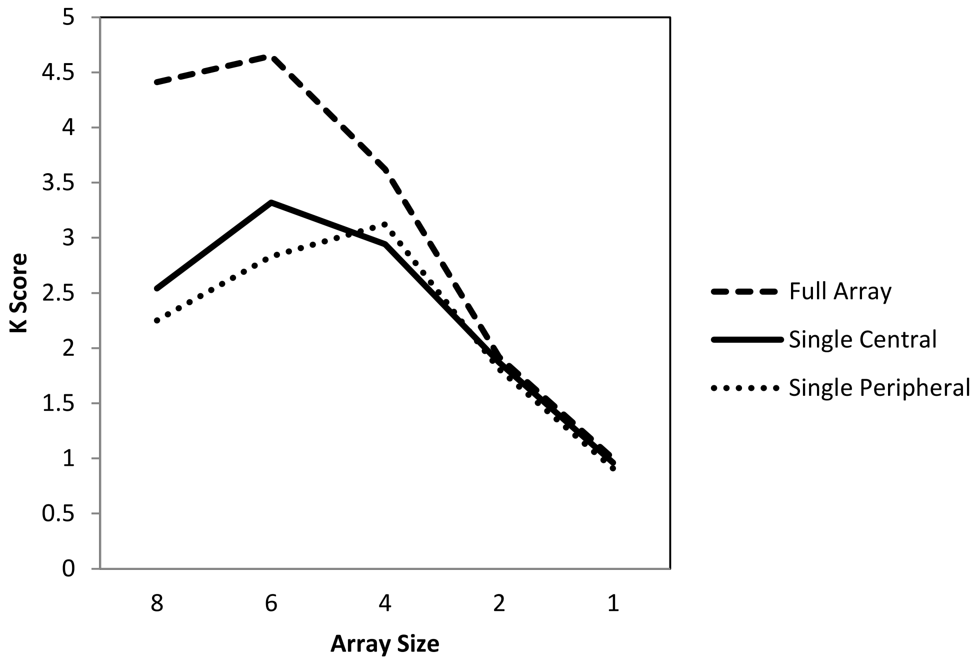


Figure 3.6. The distribution of K Scores in each condition. The higher the K score, the larger the working memory capacity storage was.

Due to the previous raw data analysis showing no effect of retrieval context, a simple analysis was conducted on the K-Scores to see if any effects were present. A 3 (retrieval condition) x 5 (array size) repeated measures ANOVA was conducted on the K-Scores showing a significant main effect of retrieval context ($F(2,9) = 10.071, p= .005, partial\ \eta^2 = .691$) and also a significant main effect of array size ($F(4,7) = 278.736, p< .001, partial\ \eta^2 = .994$). There was no interaction effect present ($F(8,3) = 2.650, p =.228, partial\ \eta^2 = .876$). Please see Table 3.2. for the averages of each individual K condition.

Bonferroni post hoc analyses on the retrieval conditions revealed a significant difference between the full cued array condition (M =2.72, SD=96) and the single peripheral location condition (M =1.93, SD=78, *p=.012*), with the full cued arrays having a higher K score than the single peripheral condition. A significant difference between the full cued array condition and the single central condition (M =2.07, SD=.61, p=.003), again with the full cued arrays having the higher K score. No significant difference was found between the single peripheral location condition and the single central condition (*p=1.00*).

This indicates that although there were no significant differences in the raw scores between the performances in each condition, there was a difference in the k-scores of each condition, suggesting higher k-scores for the full arrays.

Bonferroni post hoc analyses on the array size data also demonstrated that most array size differences were significant (all p<.05) except the differences between array sizes 2-8 (*p=.088*), 4-6 (*p=1*), 4-8 (*p=1*), and 6-8 (*p=1*). It could be suggested that once the participant had hit their capacity limit of 3-4 items, then there was no difference in storage of the higher array sizes indicating that approximately 3-4 items were stored regardless of array size. Please see Table 3.2. for averages of each condition.

3.7.6 K-Score Correlations

Table 3.3. Means and standard deviations of a combination of array sizes 4, 6 and 8.

4, 6 and 8 Full Array Average	4, 6 and 8 Single Central Array Average	4, 6 and 8 single Peripheral Array Average
4.22 (1.08)	2.53 (.98)	2.43 (1.22)

Table Notes:

Average scores of array sizes 4, 6 and 8 were taken across each retrieval context condition. Array sizes 1 and 2 were not used in this analysis as they displayed ceiling effects of over 90% performance levels. Correlations were then conducted on the data to look at the relationships between the retrieval conditions. There were no significant correlations between the full cue retrieval context and the single central retrieval context (*r =.487*, *p=.129*). The correlation between the single central and single peripheral retrieval context was significant (*r =.621, p=.018*) indicating a positive correlation between the two single retrieval conditions. There were no significant correlations between the full cue retrieval context and the single peripheral retrieval contexts (*r =.003, p=.992*). Please see table 3.1. for the averages of each retrieval context. The links between the single retrieval conitions but not with the full cued condition indicates that these types of reteival conditons could be measuring working memory capacity in a different way.

3.8 Discussion

The current experiment aimed to investigate the importance of retrieval context within working memory change detection paradigms and hoped to discover which one of three different retrieval conditions were the most appropriate to use to assess visual working memory capacity. The change detection protocol identified by Luck and Vogel (1997) was used and adapted to include three different retrieval contexts of a full array, single central array and single peripheral location array. It was predicted that the single central retrieval probe would be the most appropriate retrieval context to use as participants would perform more accurately in this condition, however it was found that this was not the case and no retrieval context effects were found from the initial raw data analyses. It was also predicted that array size 8 would be the array size of which participants would score the lowest. This prediction was supported with array size 8 having the lowest performance levels and results also indicated ceiling effects with array sizes 1 and 2. With regards to the K scores, it was predicted that higher K scores would be shown in the single central retrieval condition, demonstrating higher working memory capacity with no influences of spatial cues or the full arrays. This prediction was not supported as there were significant differences between the full arrays and both of the single probe retrieval conditions with the full array condition demonstrating a higher K score. The lack of correlations between the full and single probe conditions could indicate that there is an advantage within one condition. Suggestions can be proposed that the full array condition does have a spatial advantage, meaning that it will not correlate with the single retrieval conditions.

As no initial effect of retrieval context was found, the current results show a surprising contrast to the findings of Wheeler and Treisman (2002). In this research, it was demonstrated that single retrieval probes could be more accurately recalled as binding errors (of colour and location) would be reduced with the use of only one retrieval probe. The current study demonstrated that this was not the case, suggesting no differences being present between each retrieval context with regards to the raw score analyses. However, analyses of the K scores indicated a larger K score for the full array retrieval conditions, contrasting the research of Wheeler and Treisman (2002). This could suggest a spatial advantage over the full retrieval arrays and therefore this condition will not be used for the remainder of the thesis and a single retrieval probe will be used instead to eliminate any advantage of such spatial cues and binding errors.

Within their research, Wheeler and Treisman (2002) did not distinguish between where the single retrieval probe was positioned and did not specify whether a peripheral location or a central location probe would be more beneficial to participants; therefore, the current study investigated this. The current study has added to this literature by demonstrating that there are no differences between the recall of single central and single peripheral retrieval contexts.

Both the current study and the study by Wheeler and Treisman (2002) used the basic paradigm created by Luck and Vogel (1997) therefore it was hoped that results would be similar. The current study has given a contrast to the work of Wheeler and Treisman (2002) suggesting that firstly, binding errors may not be the primary explanation for the errors of memory recall and secondly, single probe trials appear to have no advantage over the multiple probes.

As the K score analyses found significant differences between the single and multiple retrieval arrays within the current study, they do show support for the findings of Brady and Alvarez (2011) and Jiang et al. (2000). Brady and Alvarez (2011) suggested that when people look at an array consisting of multiple probes, other items in the array can affect how well the array is recalled. This type of influence means that participants pay attention to all items in an array and a bias can occur when trying to recall items from memory if confusion is caused between the differences of the encoding and retrieval items. Current findings are in support of this with larger K scores for the full arrays compared to both of the single retrieval conditions. However, it can be noted that the influence of other items in an array may not always be a positive thing to note. As current researchers are aiming to create an accurate measure of visual working memory capacity without any influence of spatial memory or the influences of other items in an array, the full retrieval condition will not be used for the remainder of the doctoral thesis. The higher K scores for the full array condition indicates that there could be some form of visuospatial advantage when being presented with multiple retrieval probes on the same array. This advantage would need to be considered in all subsequent analyses throughout the current doctoral thesis and any differences in results could be due to the way the encoding and retrieval arrays are being presented. As a way of eliminating the advantage of other items in the array sequence, single retrieval arrays will be used in the remainder of the thesis as a more accurate measure of visual working memory capacity.

One difference between the current study and Brady and Alvarez (2011) was the types of stimuli used. The current investigation used a well-established change detection paradigm from Luck and Vogel (1997) whereas Brady and Alvarez (2011) created their own stimuli which may not have been widely used in different contexts. It may be an advantage to carry out the study of Brady and Alvarez (2011) using the stimuli of Luck and Vogel (1997) to see if similar results occur with the use of a procedure that has a different full array configuration to Luck and Vogel (1997).

Similar to Brady and Alvarez (2011), Jiang et al. (2000) also concluded that multiple probe arrays present an advantage. The results from the current investigation again do not support this notion.

Jiang et al. (2000) suggested that colour memory (visual memory) can rely upon location memory (spatial information) to increase memory performance and recall. This is because people will pay attention to the spatial organisation of the material as well as the coloured details. For the current experiment, the results were in support of this with the full arrays presenting larger K scores. This again indicates to potential advantage of using spatial ques within an array and leads current researchers to eliminate full retrieval arrays from the remainder of the thesis.

As there was a decrease in performance levels for array sizes 4, 6 and 8 in the current study, this suggests that the Discrete Slot Model (Luck and Vogel, 1997) is the more appropriate model to best describe the visual working memory capacity in the current quantitative change detection task. As more items have to be remembered with the larger set sizes, performance levels decrease and K-Values decrease as the slots are filled. When capacity reaches the level of 3-4 items, the remaining items simply do not get stored and capacity is reduced.

If a shared resource account (Bays et al., 2009) had been used, then the array sizes would have equal performance as the allocation of resource use would be equal across all items in the array. This would have meant that all items in the array would have been remembered no matter how many items were in the array. The next chapter of the current doctoral thesis will utilise the Shared Resource Model using a different type of change detection task which looks at small changes in visual arrays.

Improvements and Future Research

A potential limitation of the current investigation is that the encoding intervals of the stimuli were not varied. Luck and Vogel (1997) had suggested that an encoding time of 500 milliseconds was sufficient to allow the encoding of all items and that there were no differences between the 100 millisecond and 500 millisecond encoding interval. However, recent research from Lin and Luck (2012) used a 100 millisecond interval in their research successfully and did not use the original 500 millisecond interval as proposed by Luck and Vogel (1997), showing that 100 milliseconds was enough time to encode all visual information within an array. It may be of benefit to repeat the current investigation using a 100 millisecond encoding interval to discover if any effects are present with more updated stimuli.

The current investigation used array sizes 1, 2, 4, 6 and 8 to assess the different retrieval contexts in visual working memory capacity. These array sizes were taken from the original work of Luck and Vogel (1997) as this work formed the basis of the current doctoral thesis. A proposal for future research could be to include other array sizes such as array size 5. Lin and Luck (2009) used array size 3 successfully in their work on visual working memory, finding that similarity in items lead to improved performance on the change detection task. Lin and Luck (2009) also used other shapes such as diamonds which could have also been used in the current change detection task to look at the effect of colour change detection of different shapes. However, researchers must also consider how the use of different shapes could affect the way the task is presented, for example increasing the possibility of binding errors. By using different shapes and colours, participants would have to bind these features within memory, potentially causing errors if these bindings were disrupted.

3.9 Conclusion

The current investigation looked at the retrieval contexts within a visual change detection task. As the full arrays were shown to potentially have an advantage over the single retrieval probes, current researchers will use single central retrieval probes in the remainder of the doctoral thesis. This is due to the fact that the advantage from the full array may be enough to improve working memory capacity due to the influence of other items in the array (spatial configuration). As Wheeler and Treisman (2002) did find an advantage of single retrieval probes, the next stage of the doctoral thesis will use single retrieval probes instead of multiple ones. The use of the single central retrieval probes will eliminate any spatial advantage there may be with regards to the single peripheral probes. In future studies during the current doctoral thesis, researchers will be considering whether the paradigm by Luck and Vogel (1997) is purely a visual task before using this task in a developmental setting. Before using this change detection task further, and to avoid any use of spatial memory, current researchers will eliminate the use of the full retrieval arrays with a cue and also the single peripheral location retrieval probes as these can also rely on spatial cues. By using only single central retrieval probes, the use of spatial (location) cues can be eliminated so that the information presented purely visual based as participants will have to pay attention to colour only.

During the current study, as set size 8 was poorly performed and set sizes 1 and 2 were very accurately performed creating ceiling levels, current researchers will use only the size 6 and size 4 arrays in the next stage of the current research. This will ensure that the change detection task consists of the appropriate level of difficulty for the adult population.

3.10 Chapter Summary

The current chapter has piloted the quantitative change detection that will be used for the remainder of the thesis, suggesting the use of a single central retrieval probe to be the most appropriate to use in the remainder of the thesis. In an attempt to justify an appropriate retrieval context, researchers found no difference between multiple probe retrieval arrays and single probe retrieval arrays, contradicting the previous literature (Wheeler and Treisman, 2002). Reasons were provided for the use of the two specified set sizes of 4 and 6 and also the use of the single central retrieval probes for further investigation. In the next chapter, the second visual change detection task will be piloted. This task is concerned with the size changes in different shape arrays, assessing qualitative changes in visual arrays from the Shared Resource Model (Bays et al., 2009).

CHAPTER 4

Qualitative Preliminary Studies

4.1 Chapter Overview

Chapter 3 investigated a quantitative change detection task and ran the pilot study to look at appropriate retrieval contexts which could be used in the remainder of the thesis. Results concluded that a single central retrieval context to be the most appropriate to use, in line with past research literature findings which indicated that multiple probes could cause issues with memory errors. The current chapter now introduces the pilot protocol which employs the contrasting qualitative changes in working memory stimuli, using another type of change detection task. In this task, participants will be asked to assess the size changes of stimuli, ranging from 5% changes to 25% changes in shape size. It is hoped that results can give an indication of the appropriate percentage changes needed for remainder of the doctoral thesis so that this task can have the appropriate qualitative visual working memory demands.

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4.2 Background

The Shared Resource Model (Bays et al., 2009) contrasts the previously discussed Discrete Slot Model (Luck & Vogel, 1997) by focussing upon the resolution of the representations within working memory as well as the number of items that could be stored. This model defines working memory capacity in terms of the precision of the stored representations and proposes that there is no upper limit to the amount of items that can be stored. This is because a memory resource is shared equally between all 'to-be' remembered items (Bays & Husain, 2008). The Shared Resource Model has been investigated using small changes in visual arrays including features such as size, location and orientation as these aspects can be measured with very fine precision.

Awh, Barton and Vogel (2007) investigated qualitative change detection tasks from a different perspective. Researchers here suggested that it is not just recall precision alone which can decline with small changes in stimuli, but also errors known as comparison errors can increase causing the decline in working memory capacity. In their experiment, Awh et al. (2007) asked participants to view shaded cubes, random polygons, Chinese characters and coloured squares, all of which were seen to have a different levels of complexity. Performance was assessed when participants had to detect changes between both similar and non-similar stimuli. Similar stimuli consisted of changes that occurred within the same type of stimuli, for example a Chinese character changed to another Chinese character. Non-similar changes were changes that were detected between the types of stimuli, for example if a square changed to a Chinese character. High sample-test similarity, in particular between the same category items, was seen to cause comparison errors in memory as participants would make error judgements when trying to retrieve the highlighted item from memory. For the creation of the current change detection task, the possibility of comparison errors with multiple array sizes needs to be considered.

Another way of assessing the qualitative aspects of working memory is to look at the detection of precise details of the representation presented. Zhang and Luck (2008) used a colour wheel paradigm which enabled participants to point to the exact colour they recalled. A wheel meant that precision was measured by the difference between the encoding colour and the colour that was recalled by the participant. Results demonstrated that the precision of working memory declined from set size 3 to set size 6 suggesting that at set size 6, all items are stored but with a smaller amount of the resource. Zhang and Luck (2008) incorporated both the Shared Resource model and the Discrete Slot Model as an explanation for results, suggesting that memory capacity consisted of a small set of discrete fixed-resolution representations, where each slot is allocated the same amount of resource.

In a different visual working memory context, Scolari, Vogel and Awh (2008) used a change detection task to assess both qualitative and quantitative changes in stimuli, in relation to perceptual expertise. Researchers, here used images of upright faces, inverted faces and shaded cubes which were divided into two categories – a within condition (same category) and a between condition (different categories). These enabled researchers to look at the difference of both small within category changes and large between category changes. Results suggested that perceptual expertise and prior knowledge of the stimuli enhances the resolution of working memory but not the number of items stored, again suggesting a dynamically distributed resource. Scolari et al. (2008) suggested that because the K-Capacity scores for the within category conditions were lower than the between categories, this could suggest comparison errors between the stored and retrieved stimuli, for example, the comparison errors as previously suggested by Awh et al. (2007).

Phillips and Hamilton (2001), Thompson, Hamilton, Gray, Quinn, Mackin, Young and Ferrier (2006) and also Hamilton (2013) had previously suggested a contrasting way of measuring small qualitative changes in mnemonic stimuli, and this is a key study regarding the development of the current qualitative memory investigation. Although this discussion was related to the developmental fractionation within working memory, a qualitative task labelled the Size Just Noticeable Differences task was used to assess the smaller changes in visual arrays. For this task, participants are shown an encoding square which then disappears for a specified maintenance interval. At retrieval, another square is presented and participants have to decide if this square is bigger, smaller or whether there has been no change compared to the first square previously shown at encoding. As this task assesses qualitative changes, the difference in changes can range from 5% to 25% in size.

Thompson et al., (2006) used the size JND task within a clinical context to show that the task can be used to assess visual working memory. They investigated the memory resources, associated with the size JND, using participants with euthymic bipolar disorder. It was concluded that the size JND was a good measure of pure visual working memory, due to the high correlations with the Visual Patterns Test and concurrent lack of correlation with executive measures of working memory. This suggested that the size JND task potentially uses visual memory resources only and therefore this could be used to assess visual working memory where high resolution representation was required (see also Dean, 2008; Dent et al, 2010; and McConnell & Quinn, 2004)

Bae and Flombaum (2013) also assessed visual working memory efficacy in maintaining high fidelity representations. They used a simple change detection paradigm (similar to Luck and Vogel, 1997), but as well as assessing colour changes, they assessed size changes of circles and triangles. The qualitative size change detection tasks allowed researchers to manipulate the stimuli to show small changes, such as a 10% increase or decrease in shape area. From this investigation, it was found that even changing the array size from 1 to 2 items could decrease performance in working memory, therefore any larger array sizes may not be useful to use. For the current thesis, only array sizes 1 and 2 will be used as they demonstrate the most appropriate complexity and task demands. The decrease in performance from array size 1 to array size 2 suggests that the Shared Resource Model (Bays et al., 2009) to be an alternative view to discrete slot accounts. The Discrete Slot Model (Luck & Vogel, 1997) would suggest no array size differences between array size 1 and 2, indicating that the current results cannot be explained by this approach. The Shared Resource Model is a more appropriate explanation as this approach suggests decreases in performance even at lower array sizes due to the decrease in the amount of resource allocated to each item (meaning a less precise representation is stored).

Bae and Flombaum (2013) used a set size of 2 which contained two objects having either the same of different integral features (features that can be manipulated independently but are not perceived independently). By assessing the contribution of integral features they could assess performance when correspondence errors occurred. Unlike with the comparison errors of Awh et al. (2007), correspondence errors refer to the similarity of two items in an encoding array. The comparison errors from Awh et al. (2007) refer to the similarity between the encoding and retrieval stimuli. As it was discovered that shapes with similar integral features caused more correspondence errors, different shapes were used (e.g. one circle and one triangle) to eliminate any possibility of correspondence errors in the retrieval phase when completing qualitative working memory tasks.

Bae and Flombaum (2013) concluded that a shared resource model was the most appropriate model to discuss qualitative changes in the stimuli. If a slot model had been accountable then all items in both size 1 and size 2 array would have been remembered with nearly 100% accuracy as working memory capacity is seen as approximately 3 to 4 items (Luck and Vogel, 1997). As this was not the case, and memory performance of the 1 and 2 items was different, shared resource accounts can be used to explain the storage of the fine grained details.

4.3 Rationale for Study 2a and 2b

The aim of the current investigation is to pilot the qualitative change detection task and assess performance of this paradigm to see if performance levels are changed using array sizes 1 and 2. It is aimed to pilot the shape stimuli in order to determine which change sizes would give a performance of close to 75-80% and thus avoiding floor and ceiling effects. The paradigms from Thompson et al. (2006) and also Bae and Flombaum (2013) will be combined. The size of the shapes will be assessed using a similar task to that of Bae and Flombaum (2013); however, the size changes will be taken from Hamilton (2013) and Thompson et al. (2006). Participants will be shown an encoding array of 1 or 2 shapes and will have to decide if a retrieval single shape is either bigger or smaller than its equivalent shape in the memory array. Two different maintenance intervals will be used. As study 1 used a 900 millisecond maintenance interval, study 2a will use a 900 millisecond maintenance interval. Study 2b, however, will use an extended 4000 millisecond maintenance interval to look at any effect of the extended maintenance interval as this interval. The 4000 millisecond interval will be used as this interval is planned for the interference paradigms during the next stage of the thesis progression.

In each array size of 2, different shapes (circles, squares, triangles) will be used to reduce correspondence errors as suggested by Awh et al. (2007) and also by Bae and Flombaum (2013). As size can be measured to the nearest percentage change, this will be used to assess the ability to represent and maintain in short term memory small continuous or qualitative changes. From this initial research, it is hoped to identify which size change procedures are the most appropriate to use in the remainder of the thesis.

4.4 Predictions

1) There will be a difference in performance associated with the array size, 1 shape versus 2 shape stimuli in the memory array.

2) In addition it is anticipated that performance will show decline in the longer maintenance study (2b).

4.5 Method

The methods for study 2a and 2b were the same except study 2a used a 900ms maintenance interval and study 2b used a 4000ms maintenance interval within the change detection protocol.

4.5.1 Design

In both study 2a and 2b, a 2 x 5 repeated measures design was used as all participants took part in all experimental conditions. Factor 1 was array size consisting of two levels – array size 1 and array size 2. Factor 2 was percentage change consisting of 5 levels – 25%, 20%, 15%, 10% and 5% change.

4.5.2 Participants

14 participants (7 males and 7 females with a mean age of 30 and a standard deviation of 6.77) took part in study 2a. 10 participants took part in study 2b (7 females and 3 males with a mean age of 27 and a standard deviation of 5.23). Participants were from the area of Newcastle-upon-Tyne and had no condition of colour blindness or photosensitive epilepsy.

4.5.3 Materials

4.5.3.1 Perceptual Task (Paper Based)

In order to familiarise themselves with the change detection protocol and to additional include a perceptual screen, the participants were initially given a perceptual size detection task. This paper based task contained images of pairs of squares and participants had to decide if the pairs of squares were the same or different in size. For each percentage change, 10 pairs of squares were shown and participants could work through the task at their own pace. Please see appendix C for an example of this task.

Participants had to score at least 70% correct on the perceptual task to progress onto the computer based tasks so that floor effects were avoided. No statistical analyses were conducted on these paper tasks as scoring was only used to exclude people who did not score above the 70% needed for the computerised task.

4.5.3.2 Qualitative Size Change Detection Tasks

There were three qualitative change detection components presented to participants which assessed size changes in visual arrays. The practice task (first task) consisted of only 12 trials and scores were not used during any analysis procedure as this was purely for participants practice purposes. The second task (experimental task) included trials for array size 1. These were presented in 3 blocks, with each block containing 24 trials of squares, circles or triangles. For each block there were 2 trials containing 25% changes, 2 trials containing 20% changes, 4 trials containing 15% changes, 8 trials containing 10% changes and 8 trials containing 5% changes.

The third task (experimental task) included trials for array size 2. These were presented in 3 blocks in this task with each block containing 24 trials of squares, circles or triangles. For each block there were 2 trials containing 25% changes, 2 trials containing 20% changes, 4 trials containing 15% changes, 8 trials containing 10% changes and 8 trials containing 5% changes. Researchers decided not to counterbalance the administration of array sizes 1 and 2 due to the task difficulty. It was required that participants understood the task and therefore array size 1 was given to the participant before the more challenging array size 2. Please see Figure 4.1. for an example of this task. The total score for each experimental task could be 72.

4.5.3.3 Trials for Study 2a

Each trial consisted of the presentation of an encoding array of either 1 or 2 shapes, presented for 500 milliseconds on a computer screen. For both array size 1 and 2, the location of the encoding shapes was randomly allocated to one of eight possible locations around a circular location. A maintenance array was then presented for 900 milliseconds and this contained one central cross. A single central probe retrieval array was presented for 3000 milliseconds or until the participant pressed the appropriate response key on the keyboard. Participants had to press ‘p’ if the shape was bigger and ‘q’ if the shape was smaller than the corresponding one in the encoding or memory array.

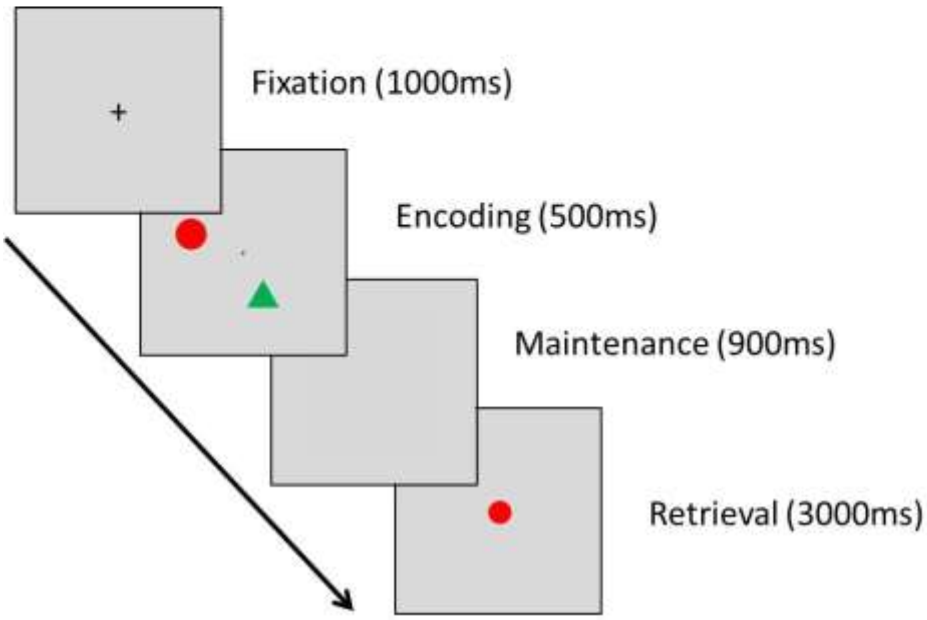

Figure 4.1. An example of one trial containing the shape stimuli.

Trials for Study 2b

The trials for study 2b were the same as study 2a except the maintenance interval was extended to 4000 milliseconds.

4.5.4 Procedure – Both Study 2a and 2b

The procedure for study 2a and study 2b were identical except for the increase in a maintenance interval during study 2b.

The current investigation was ethically approved by the University Health and Life Sciences Ethics Committee. The total testing session lasted 30 minutes. An information sheet and consent form was given to participants before the investigation began. The size change detection task was fully explained to participants before the testing phase began. Please see Appendix B for the task instructions given to participants.

Before any computer testing began, participants were given a perceptual, paper based size detection task containing images of squares that varied in size. Participants had to identify whether these pairs of squares were the same size or different. This was then checked by the researcher to ensure the instructions of the task were fully understood. Any participant who did not complete this perceptual task to the criterion level did not take part in the computer task.

Participants were then asked to work through three computer task themselves, pressing the appropriate keys on the keyboard when prompted. When the practice task and first array task was finished, the researcher opened the next programme ready for completion by participants. The aim of each task was to identify if the centrally located probe stimulus was larger or smaller than its equivalent shape in the memory array.

When testing was completed, participants were notified on screen and were asked to wait for further instructions from the researcher. At this point testing had finished and participants were fully debriefed, including a reminder of the right to withdraw and how to contact the researcher if needed.

4.5.4.1 Scoring of Each Qualitative Change Detection Task

As each block contained 24 trials of different size changes, 1 point was given for a correct score and a score of 0 was given for an incorrect score. Performance levels were calculated for each percentage change to standardise the scoring. This allowed a comparison between the different percentage changes to take place as each percentage change had a different amount of trials. A total score of 72 could be given for each experimental task of array size 1 and array size 2.

4.6 Results – Study 2a (900ms Maintenance Interval)

As this was a pilot study to investigate which size changes could be detected by participants, a simple analysis was first conducted using the data.

Performance levels were calculated for each percentage change (overall) so that comparisons could be made between the 5% changes and the 25% change. Please see table, 4.1., for the means of each percentage change which also indicate ceiling effects for percentage changes of 25% and 20%.

Post Hoc Analyses

Where post hoc analyses were needed for a main effect given from an ANOVA, the Bonferonni function within the ANOVA SPSS analysis was used which automatically adjusts the alpha level accordingly. When following up an interaction effect, this Bonferroni function was not used and instead, paired smaples t-tests were conducted with the appropriately adjusted p values for each correction (for example, alpha/number of hypotheses tested).

A 2 (array size) x 5 (percentage change) repeated measures ANOVA was applied to the data, demonstrating a significant main effect of array size (*$F(1,13)=22.410$, $p<.001$, partial $\eta^2=.633$*. A significant main effect of percentage change (*$F(4,10)= 29.712$, $p<.001$, partial $\eta^2 = .922$*).

Bonferroni post hoc analyses revealed significant differences between the percentage changes of 25% and 15% ($p=.015$) and 25% and 5% ($p<.001$).

No interaction was found (*$F(4,10)= .391$, $p = .810$, partial $\eta^2 = .135$*).

Table 4.1. Means (and standard deviations) of the performance levels of each percentage change for both array size 1 and array size 2 in study 2a (900 millisecond maintenance interval).

	Array Size 1	Array Size 2	Total
25% Change	97.60(6.17)	92.71(10.99)	95.14(7.23)
20% Change	95.14(10.39)	90.29(12.85)	92.71(10.46)
15% Change	89.86(13.61)	80.79(8.37)	85.32(6.90)
10% Change	88.36(9.30)	82.36(10.75)	85.35(9.36)
5% change	82.71(11.60)	74.07(12.43)	78.39(10.81)
Total	90.72(7.62)	84.04(6.84)	

Table Notes:

4.7 Results – Study 2b (4000ms Maintenance Interval)

As this was a pilot study to investigate which size changes could be detected by participants, a simple analysis was first conducted using the data. Any data which was seen at chance level (below 50% performance) was not used during the analysis stage.

Performance levels were calculated for each percentage change (overall) so that comparisons could be made between the 5% changes and the 25% change. Please see Table, 4.2., for the means of each percentage change.

Table 4.2. Means (and standard deviations) of the performance levels of each percentage change for both array size 1 and array size 2 in study 2b (4000 millisecond maintenance interval).

	Array Size 1	Array Size 2	Total
25% Change	93.30(16.12)	95.00(11.20)	94.15(13.61)
20% Change	93.30(11.63)	90.00(21.08)	91.65(12.44)
15% Change	94.20(10.42)	79.80(5.59)	87.00(7.85)
10% Change	89.70(8.68)	83.10(13.65)	86.40(9.74)
5% change	86.50(11.30)	75.80(6.75)	81.15(7.94)
Total	91.40(9.18)	84.74(9.33)	

Table Notes:

A 2 (array size) x 5 (percentage change) repeated measures ANOVA was applied to the data, demonstrating a significant main effect of array size (*F(1,9)=19.348, p=.002, partial* η^2*=.683).* Array size 2 (M = 84.7, SD = 9.33) was less accurately performed than array size 1 (M = 91.4, SD = 9.18). Please see Table 4.2. for means and standard deviations. No main effect of percentage change (*F(4,6)= 3.845, p=.070, partial* η^2 *= .719.* An interaction between array size and percentage change was found (*F(4,6)=21.240, p = .001, partial* η^2 *= .934*).

To follow up the significant interaction of array size and percentage change, two repeated measures ANOVAs were conducted to look at any differences between the larger array sizes (25% and 20%) and smaller array sizes (15%, 10% and 5%).

A 2(percentage change - 25%, 20%) x array size (array sizes 1 and 2) was conducted to look at any effects of the larger changes. Results revealed no effects of array size *F(1,9) = .056, p=.818, partial* η^2 *=.006* and no effects of percentage change, *F(1,9)=.446, p=.521, partial* η^2 *=.047.* No interaction of array size and percentage change was present *F(1,9)=.367, p=.560, partial* η^2 *=.039.*

A 3(percentage change – 15%, 10%, 5%) x array size (array sizes 1 and 2) was conducted to look at any effects of the smaller changes. Results revealed a significant main effect of array size, *F(1,9)=51.036, p<.001, partial* η^2 *=.850.* Array size 1 had a larger mean of 91.40 (SD=9.18) compared to array size 2 with a mean of 84.74 (SD=9.33). A significant main effect of percentage change, *F(2,8)=4.746, p=.044, partial* η^2 *=.543.* Bonferroni post hoc analyses revealed that the 10% size change had a higher mean of 86.40 (SD=9.74) compared to the 5% size change with a mean of 81.15 (*SD=7.94, p=.010*).

The interaction between array size and percentage change has been shown to come from the differences in array size and percentage change with regards to the smaller array sizes whereas no differences are present with the larger array sizes. Please see Figure 4.2. for a representation of this interaction.

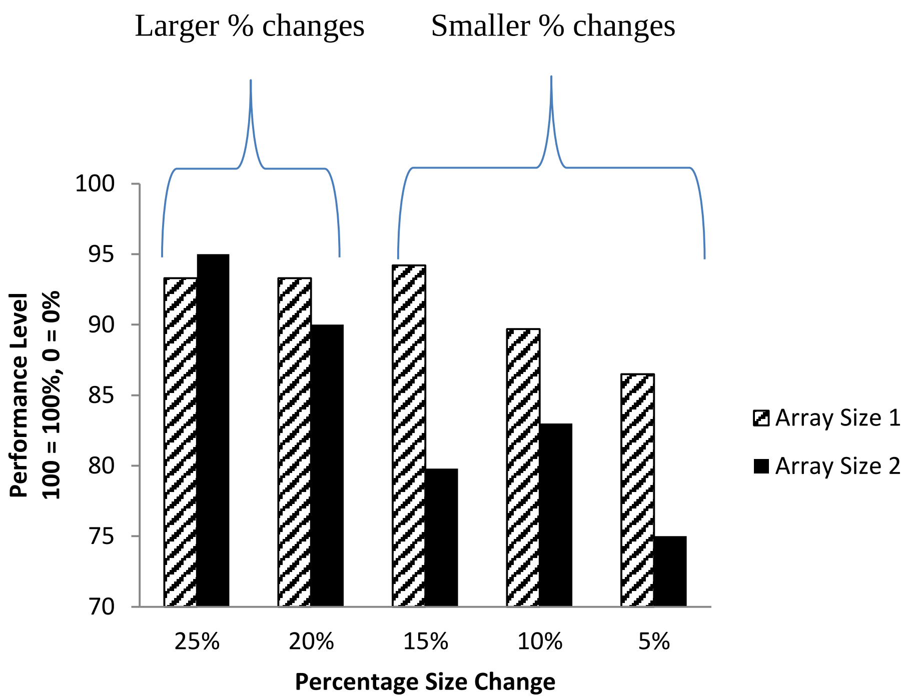

Figure 4.2 The interaction between percentage change and array size in study 2b

4.7.1 Study 2a and 2b Comparison

To compare the results of study 2a and study 2b, a 2(array size) x 5(percentage change) x 2(maintenance internal) ANOVA was conducted. Both array size and percentage change were within-subjects' factors and the maintenance interval was used as a between-subjects' factor.

Main Effects

Results demonstrated a significant main effect of array size, $F(1,22)=35.449$, $p<.001$, *partial* $\eta^2=.617$. Array size 1 had a significantly larger mean of 91.06 compared to the mean of array size 2 of 84.40.

A main effect of percentage change was also found, $F(4,19)=22.475$, $p<.001$, *partial* $\eta^2=.826$. Bonferroni post hoc analyses demonstrated that the 25% change, with a mean performance of 94.64 (SD=11.40) was significantly larger than the mean performance of the 5% change mean of 79.68 (SD=6.73, p<.001). The 20% change, with a mean performance of 92.48 (SD=10.88) was also significantly larger than the mean performance of the 5% change (p<.001). The 25% change was shown to have significantly larger than the mean performance of the 10% change of 85.72 (SD= 12.03, p=.001). The 20% change was significantly larger than the 10% change (p=.014). The 25% change was significantly larger than the 15% change of 86.13 (SD=12.44, p=.004).

No main effect of maintenance interval was found $F(1,22)=.045$, $p=.883$, *partial* $\eta^2=.002$.

Interactions

A significant interaction between array size and percentage change was found, $F(4,19)=3.811$, $p=.019$, *partial* $\eta^2=.445$.

Paired samples t-tests were conducted to look at any differences between the percentage change performance levels of each array size.

Results suggested that there were significant differences between the 15% changes of each array size t(23) = 3.985, p=.001, the 10% changes of each array size, $t(23) = 3.495$, $p=.002$ and also the 5% changes of each array size $t(23) = 4.756$, $p=<.001$. However, there were no significant differences between the 25% changes of each array size, *t(23) = 1.141, p=.226*, and also the 20% changes of each array size, *t(23) = 1.005, p=.325*.

The interaction is being caused by the significant differences of the smaller array sizes whereas opposing results occur with the larger array sizes, presenting no differences. Please see Figure 4.3. for a graph of this interaction.

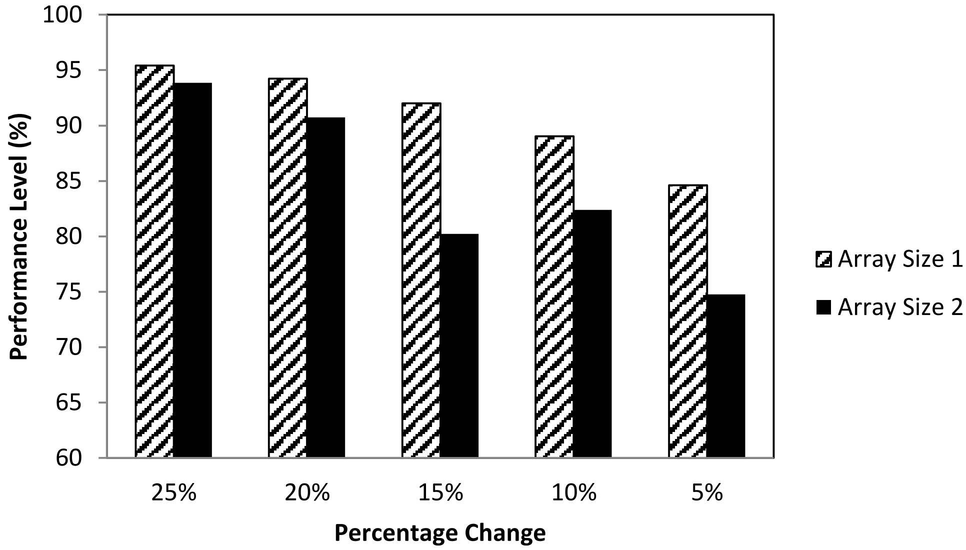

Figure 4.3. The interaction between array size and percentage change in the comparison of study 2a and 2b.

4.8 Discussion

This current preliminary investigation aimed to identify the extent to which array size and maintenance interval impacted upon change detection performance within a qualitative short term visual memory protocol. In addition, it aimed to establish the parameters for the sizes of changes which would enable performance to be uninfluenced by floor or ceiling effects in two studies, using a 900 and a 4000 millisecond maintenance interval during a qualitative change detection task.

Initially a 900 millisecond maintenance interval was used to follow the same procedure as Bae and Flombaum (2013), however, this was then extended to a 4000 millisecond maintenance interval to utilise the change detection in a longer context with regards to the next study of the doctoral thesis. As study 4 will use a 4000 millisecond maintenance interval to look at the representations in working memory, a comparison was made of the original timings of Bae and Flombaum (2013) 900 millisecond interval and also the 4000 millisecond maintenance interval to see if any detrimental effects occur.

Similar to Bae and Flombaum (2013), when a 900 millisecond maintenance interval was used, the current investigation found a significant difference between the percentage changes. This suggested that in both Bae and Flombaum (2013) and in the current study, participants could detect very small changes (qualitative changes) in shape stimuli. However, one point to note is that Bae and Flombaum (2013) only had a small increase/decrease of 10% and they did not use stimuli that had very small 5% size changes. This is where the current study expands on those findings of Bae and Flombaum (2013) and presents further data to support the detection of small qualitative changes in visual arrays.

The current study also aimed to look at the difference between a 900 millisecond and 4000 millisecond maintenance interval and found that the 4000 millisecond maintenance interval provided participants with a time limit that reduced working memory performance, in particular with regards to array size 2. As Bae and Flombaum (2013) did not use a long 4000 millisecond maintenance interval, it is difficult to compare the current findings to Bae and Flombaum (2013) based on the maintenance interval only. It could be suggested that the interaction between array size and percentage change size reflects the fundamental distinction between Quantitative – categorical (large) change detection representation and Qualitative -

high resolution representation within visual short term memory. When the change size is larger, approaching a categorical level or large change in size, the impact of array size is reduced. However, when high resolution representation is required in the context of small size changes, then array is more influential. It should be noted that in these results, even when the stimuli were designed to minimize comparison errors, performance still declined when array size increased from 1 to 2 items.

Thompson et al. (2006) did use small percentage changes, narrowing these changes to a 6% increase or decrease in the area of a shape. In their 2006 investigation, researchers used a 4000 millisecond maintenance interval to show that the size JND task could work and assess an individual's visual memory. Although similar size changes and a similar maintenance interval was used, the procedure of the current investigation was slightly different to that of Thompson et al. (2006). Thompson et al. (2006) only presented participants with one square for the encoding arrays and did not make use of any other shape. The current investigation used both array size 1 and array size 2, but also presented participants with a variety of three different shapes.

It could be suggested that the inclusion of two different shapes with a 4000 millisecond maintenance interval made the current task more difficult than that of Thompson et al. (2006). 2 shapes would mean that less memory resource is shared between each shape (item). Thompson et al. (2006) only had 1 shape meaning that the full memory resource was allocated to this one item. Looking from a Bays et al. (2009) perspective, the current task could be seen as more difficult due to the decreased precision in memory with the resource being divided between two items. To fully compare the differences between the current investigation and that of Thompson et al. (2006), a separate study would need to be conducted looking only at squares with array size 1.

Due to the possible reduction of comparison errors in set size 1 (perspectives proposed by Bae & Flombaum, 2013), task performance across the 900 millisecond and 4000 millisecond maintenance interval may have been similar simply because participants found the task to be too easy. From looking at the averages, participants did not score remarkably less than 74% across set size 1 in both maintenance intervals. With regards to the current thesis investigation, to increase task difficulty, it may be advisable to have a larger proportion of array size 2 within the change detection procedure if the task is found to not be demanding upon memory. This would make the change detection task more demanding than simply just using array size 1.

The decrease in performance from set size 1 to set size 2 does provide support for the Shared Resource Model (Bays et al., 2009). As there was a decrease in performance, it suggests that although all items are stored in memory with a given array is presented, more resource was allocated to the single item in set size 1 compared to the two individual items in set size 2. Contrasting models of working memory capacity (Luck and Vogel, 1997, 2013) would suggest that both set size 1 and set size 2 are stored with similar accuracy. These types of slot models would suggest that both set size 1 and set size 2 would not completely fill the 3-4 working memory slots, enabling high accuracy on both set sizes. As this was not the case, the slot model accounts cannot be used to account for the results of the current investigation of this qualitative change detection protocol.

<u>Improvements and Future Research</u>

A potential limitation consideration of the current investigation could be that the task used a variety of shapes, instead of just simple squares as used by Hamilton et al. (2001) and Thompson et al., (2006). The current task was based on the research by Bae and Flombaum

(2013) who used a variety of shapes, such as triangles, circles and squares, to look at shape size changes and memory errors in visual arrays. It could be questioned as to whether a similar pattern of results would be found with just using squares as Phillips and Hamilton (2001) did.

One direction for future research could be to make the current change detection paradigm similar to that of Phillips and Hamilton (2001). In this research, only squares were used to assess the size changes in visual arrays, in particular the presentation of one single central square, concluding that small changes could be detected. This would eliminate the use of 2 shapes/squares, meaning that participants would only need for focus upon the one item presented.

Although the current change detection task was created to stop potential memory errors such as correspondence errors, the task unintentionally caused participants to need to use binding abilities instead (Wheeler & Treisman, 2002), making the task more difficult than intended. As both colour and shape were used in the qualitative change detection tasks, and participants were unaware as to which shape would be presented at retrieval, the binding of the shapes and colours had to be conducted in memory. If participants were informed that the colours of the shapes would not change during the current task, this could have caused less errors within memory as the size of the shapes only would have been focussed on.

Brown and Brockmole (2010) looked at feature binding in an ageing population, suggesting that binding errors in memory can occur especially when the attentional load is increased. With regards to the next stage of the current doctoral thesis, differences in primary task performance could occur when giving participants a task such as the current qualitative change detection task (which includes binding) plus an attentionally demanding task such as a visuospatial interference task (Vergauwe *et al.*, 2009). Compared to the non-binding quantitative change detection task, the qualitative change detection task could produce more errors within memory simply based on the fact that the disruption of the blinding abilities has occurred. In future, it may be useful to use single coloured shapes, for example, black, so that the participant does not need to use the binding abilities associated with colour and shape and therefore the possibility of such errors can be reduced.

4.9 Implications for Study 4 – Qualitative Interference Paradigm

After completing study 2a using a 900 millisecond maintenance interval, it was found that participant could detect size changes as small as a 5% increase or decrease in the size of a shape. It was thought that the qualitative change detection task sizes of 25%, and to a less extent, 20%, in study 2a may be seen as not cognitively challenging enough; therefore, the 25% changed will be eliminated from the qualitative change detection tasks of the remaining doctoral studies to increase task difficulty. As the qualitative change detection task in study 4 will essentially use a 4000 millisecond maintenance interval to allow an inclusion of an interference task, current researchers decided to increase the maintenance interval in the current task so that study 2b was created. It was found that there was no difference between the percentage changes during the 4000 millisecond and 900 millisecond conditions.

Ideally, the study aimed to achieve a 75%-80% performance level. Clearly, the 25% change performance level was too high in both maintenance conditions and had to be taken out. It is proposed that if the 25% change had been used in the next investigation, the interference tasks would not be impacting upon a high resolution qualitative change detection task process as participants would more likely be using categorical comparison processes during the probe phases

4.10 Chapter Summary

This chapter piloted the stimuli and protocol which will be used during some of the subsequent experiments of the current doctoral thesis. Researchers used small changes in stimuli, of as little as 5% bigger and smaller, to demonstrate that participants could detect small changes within a qualitative change detection task. Combining the 900 millisecond and 4000 millisecond data demonstrated significant differences in the performance levels of the 25% and 5% changes in shape size.

Results have led researchers to disregard the 25% changes for the next experiment in the current doctoral thesis due to the ceiling effects presented with this percentage change. The use of the 4000 millisecond maintenance interval will continue within the dual task procedures of study 4 as this interval produced the most appropriate performance levels (75-81%) which demonstrated that the task was not too easy for participants.

The next experiment in the current doctoral thesis will look at the nature of the quantitative change detection task in more detail, focussing upon the potential inclusion of verbal representations in the task. The study will investigate whether a more multicomponent or domain specific approach can be taken with regards to representation use in the task.

CHAPTER 5

Quantitative Dual Task Experiment

5.1 Chapter Overview

Chapters 3 and 4 piloted the qualitative and quantitative change detection tasks to be used in the remainder of this thesis, giving details of the most appropriate retrieval context to use and the most appropriate size changes to use with a young adult sample. This chapter of the doctoral thesis now introduces a dual task methodology to investigate the representations used within the quantitative change detection task. The aim of this study is to try and understand the working memory architecture at use during the completion of the quantitative visual memory task and to discover if the task demands are as visual domain-specific as suggested by Baddeley (2012) and Shah and Miyake (1996) and required by Luck and Vogel (2013). It has been suggested that visual tasks may use verbal representations and domain general attentional resources (Brown & Wesley, 2013; Shipstead & Yonehiro, 2016; Vergauwe et al., 2009) and the current dual task methodology also aims to investigate this. An introduction to the dual task methodology background literature is given with the results of study 3 of the current doctoral thesis.

5.2 Background

In chapter 1, details of the two working memory models were given.

Logie (2011) created a multicomponent approach to working memory, suggesting that the phonological stores and Visual Cache remain as two individual components. However, at a closer inspection of the model, Logie suggested that visual information is inputted through an Episodic Buffer like component. This component allows the integration of visual and verbal material within memory and because of this; Logie’s approach can be seen as a more multicomponent approach to visual working memory.

When considering a more domain specific approach, the model created by Baddeley (2012) suggests that visual information may be stored on a more perceptual level and that it is directed straight into the Visuospatial Sketchpad (VSSP). This perspective is seen as a gateway account as there are no suggested influences of long term semantic involvement or executive resource processes. The domain specific approach leads researchers to conclude no direct interaction between peripheral working memory components, such as the Phonological Loop or the VSSP.

Luck and Vogel (2013) supported the views of Baddeley (2012) and defined visual working memory tasks in a recent review, suggesting that working memory tasks use visual components only. Researchers' defined visual working memory tasks as using visual representations only, and that if other types of representations were used (semantic, verbal) then this is not seen to be a visual memory task.

Shah and Miyake (1996) also proposed a more domain specific approach to working memory with their investigation looking at the separability of working memory resources for both spatial thinking and language processing tasks. In their investigation, using an interference protocols, researchers demonstrated how a spatial span task could correlate well with a spatial visualisation task (for example, a Spatial Relations Task) but not with any verbal ability measures. Similarly, the reading span task correlated well with the verbal ability measures (Verbal SAT Scores) but not with any spatial tasks. Showing how domain specific tasks could predict similar types of task (spatial tasks predicting the performance on other types of spatial tasks or verbal tasks predicting other types of verbal tasks), Shah and Miyake (1996) proposed a working memory approach whereby there are two systems within memory – one which utilised verbal information and another which utilised visuospatial information.

Brown and Wesley (2013) contradicted ideas from Luck and Vogel (2013) suggesting that visual tasks can incorporate aspects of mixed strategy use such as the use of semantics and verbal information. In their experiment, the VPT was investigated and it was found that participants could make use of semantics and verbal information when being presented with a matrix pattern. Brown and Wesley (2013) suggested that visual working memory capacity can be improved when visual tasks allow for the use of verbal coding and semantics as well as the initial use of visual information, meaning that the visual specific accounts may not be appropriate to discuss visual memory tasks. In addition, the Luck and Vogel (1997) visual working memory change detection task has come under criticism in the suggestion that semantics could be recruited when carrying out the task. Hartshorne (2008) argued that the change detection protocol could suffer from proactive interference, interference coming from several trials earlier. This would imply that the representation for the trial information is not so transient and potentially has a stable component underpinned by LTM (See Phillips & Christie, 1977; and also Lin & Luck, 2012). Should this be the case then there is scope for LTM semantics recruitment. In addition, Brady and Alvarez (2011, 2015) suggested that when the memory arrays (and probe array) affords the opportunity for hierarchical organisation then participants will make use of a more abstracted representation of the visual information in order to enhance task performance. Thus, Shipstead and Yonehiro (2016) have argued that the relationship between change detection performance and complex cognition could results from domain specific and domain general resources demanded in visual change detection protocol demands.

One conventional method employed to look at the demands a task makes upon the working memory architecture is to use a dual task paradigm. In this case, two tasks are completed simultaneously, with one task (Secondary Task) alongside (e.g. in the retention interval) of another (Primary Task).

Rudkin, Pearson and Logie (2007) used a dual task paradigm to investigate executive processes in both visual and spatial working memory tasks. The Corsi Blocks Task and the VPT were the primary tasks in this experiment with a random digit generation task being the secondary task. As both the Corsi Blocks Task and the VPT were initially not seen to involve any of verbal processing, it was suggested that the verbal secondary task would have no effect on these. However, results of the investigation demonstrated that both the Corsi Blocks Task and the VPT (in study 1) showed a decrease in performance when the random number generation was used, suggesting the use of potential generic executive/attentional resources and not just visual specific information. The Corsi Blocks dual task deficit was much greater, suggesting that this task may place a higher load upon the generic executive resources compared to the more visually related VPT.

Hamilton, Heffernan and Coates (2003) also used an interference paradigm to look at the developmental changes of the visual working memory architecture in children in relation to both visual (matrix patterns task) and spatial span tasks (Corsi Blocks Task). Four secondary tasks were used in this case - visual mask, spatial tapping, speech articulation and a verbal fluency task. Results demonstrated that working memory architecture does change between adults and children. The verbal fluency task was shown to have an effect on the visual span task (matrix patterns task) in both children and adults, suggesting an overlap in the use of both visual and executive components in working memory for all ages. However, speech articulation only affected spatial span in the children, suggesting that adults may use less phonological specific and more executive resources (or an Episodic Buffer component) within their working memory architecture for visual span tasks. As speech articulation has been suggested to only hit the Phonological Loop within memory, this could suggest that the visual span task may use a form of higher level representations bound by Long Term Memory and this may be starting to develop within the memory structure of a child. An Episodic Buffer component, instead, is one which could be used to target such higher level integrated representations within a visual span task and could also be an explanation as to why the articulatory suppression had no effect upon the higher level visual span task. The use of an Episodic Buffer component will be detailed in a later section of this chapter when work of Brown and Wesley (2013) is discussed.

Vergauwe, Barrouillet and Camos (2009) investigated visual and spatial working memory dissociations, using both spatial and visual interference dual tasks. In a series of smaller experiments, participants took parts in tasks which assessed spatial and visual processing and storage abilities.

Results from this investigation suggested a more multicomponent approach to the working memory architecture with both visual and spatial secondary tasks hitting both visual and spatial primary tasks. In particular, it was demonstrated that the spatial interference task (Bar Fit task) also affected a visual matrix task presented, indicating that this task may use recruit visual and spatial resources. Although, the spatial interference task (bar fit task) affected the results of the spatial processing task (ball movements) at a higher level than the visual processing task, visual secondary tasks also affected the spatial processing task. Vergauwe et al. (2009), however, did not look at any use of secondary task explicitly demanding verbal resources, therefore the current study aims to do this using two visual change detection tasks.

For the purposes of the current study, the Bar Fit Task (Vergauwe et al., 2009) will be used as the visual secondary task. This task was demonstrated to show interference in spatial and visual working memory; therefore, should provide current researchers with a clearer idea of which working memory components are at use when completing the current quantitative change-detection task which has been created. As visual and spatial interference effects are associated with the VSSP (Baddeley, 2012), the Visual Cache and the Inner Scribe (Logie, 2011), interference effects would show the use of any specific components during the tasks.

Interference effects are not just visual specific. Lépine, Bernardin and Barrouillet (2005) used a verbal parity task to demonstrate verbal interference effects. It was found that the administration of a simple verbal task (stating if a number is odd or even) had a detrimental effect on memory span (reading span). This task disrupted the memory of the working memory span task, leading researchers to conclude that it may not be the task itself which causes interference but the fact that attention is directed away from the primary task.
However, from their study, Lépine et al. (2005) concluded that any phonological task may have had the ability to cause disruption as interference could be concerned with the allocation of attention to each task as well as disrupting the specific working memory components involved in processing and storage. This is one question that will be addressed within the current experiment as the fundamental aim is to identify whether the verbal parity task (as used by Lépine et al., 2005) does cause interference in a visual memory paradigm through its generic attentional demands (see Vergauwe *et al.*, 2009 above).
In contrast to Lépine et al. (2005), Jones Madden and Miles (1992) suggested that irrelevant phonological speech could not disrupt any visual information stored. In their research, the repetition of the letters F, K, L, M, P, Q and R. were shown to cause no effects to the primary visual memory task. One reason for the lack of interference could be due to the components at use during the secondary irrelevant speech task. The earlier work of Jones et al. (1992) suggested that the irrelevant speech interference made demands upon the Phonological Loop alone and therefore would not disrupt any visual task which made use of the non-verbal

components. This account contrasts with that of Lépine et al. (2005). If the interference was due to the allocation of attention alone then the research of Jones et al. (1992) would show effects with the visual task. As this was not the case, the use of the verbal parity task in the research of Lépine et al. (2005) may be more verbal specific. Articulatory suppression alone may not be expected to have a cross modal effect if its generic attentional demand is low. The verbal parity task, however, demands Long Term Memory access and this demand upon attentional resources (see Unsworth & Engle, 2007; Unsworth & Spillers, 2010; Unsworth et al., 2014) may be sufficient to impact upon the primary change detection tasks in the current change detection protocols.

5.3 Rationale for Study 3

The aim of the current investigation is to investigate the cognitive resource demands of visual representation in the quantitative change detection task by using a dual task context. Adding in a secondary task, of either verbal attention (verbal parity task) or visual attention (bar fit task) will allow researchers to establish which working memory components are being used during the task. The verbal parity task (Lépine et al., 2005), will be used as verbal specific interference, and the bar fit task (Vergauwe et al., 2009) will be used as visuospatial interference as this has the potential to hit both visual and spatial working memory components. As each interference task makes use of a different working memory component, it is hoped that researchers can gain an understanding of whether a multicomponent (Logie, 2011) or a more domain specific (Baddeley, 2012) working memory model can be used here to explain the working memory architecture of the quantitative change detection task.

5.4 Predictions

1) From a Luck and Vogel (2013) view, the bar fit task (visual attention task) will have the greatest effect on the primary visual memory task.
2) From a Luck and Vogel (2013) view, the verbal parity task will not affect the primary visual memory task, meaning verbal semantics will not contribute to results. This would demonstrate a domain specific resource use as suggested by Baddeley (2012).

5.5 Method

5.5.1 Design

A 3 x 2 repeated measures design was used for the purposes of this experiment. Factor 1 was the interference type containing 3 levels – baseline, visuospatial interference, verbal interference. Factor 2 was the array size consisting of either size 4 or 6.

5.5.2 Participants

19 participants (14 females and 5 males, with a mean age of 23 and a standard deviation of 4.48) from the area of Newcastle-upon-Tyne volunteered to take part in this investigation. Those who were Undergraduate Psychology Students received four course credit points for their participation in the experiment. Participants were aged between 18 and 30 years and had no record of any condition such as photosensitive epilepsy or colour blindness as these conditions could be affected by the experimental tasks.

5.5.3 Materials

12 short e-prime programmes were created for the purposes of this experiment. These included 4 practice tasks (two primary practices, a verbal parity practice and a bar fit practice) and 4 baseline tasks (two primary baselines, a verbal parity baseline and a bar fit

baseline). 4 dual task experimental programmes were then used. Each array size (4 and 6) contained one of each of the interference procedures from Verbal Parity and Bar Fit tasks.

As well as the e-prime tasks, instruction sheets were created to explain the primary Change Detection Square Task, Verbal interference and Visuospatial Interference. These instruction sheets included example images of the tasks plus instructions of which keys to press on the keyboard for a yes/no response. See Appendices A, D and E for examples of the instructio4s for participants.

5.5.3.1 Primary Colour Change Detection Task

Array sizes 4 and 6 were used from the pilot of the quantitative stimuli (chapter 3, experiment 3) for the encoding arrays. Only central peripheral location retrieval arrays were used for the purpose of this experiment. E-Prime 2.0 was used to create each task. Please see the methods section in chapter 3 for further details of this task.

Each primary e-prime task consisted of only 20 trials. In each trial, the encoding array was presented for 500 milliseconds, followed by a maintenance array of 4000 milliseconds. Finally, a retrieval array was presented for 3000 milliseconds. please see Figure 5.1. for an example of a trial for this task.

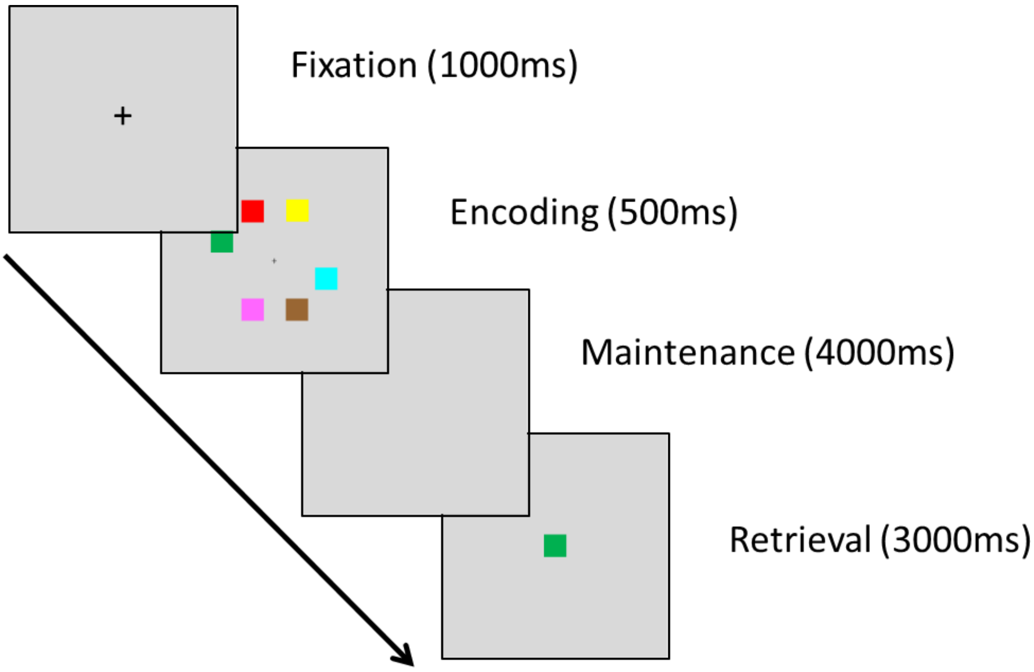

Figure 5.1. An example of one quantitative task trial containing the square stimuli.

5.5.3.2 Secondary Task, Visuospatial Attention – Bar Fit Task

A visuospatial attention task (Bar Fit Task) was presented in the 4000 millisecond maintenance interval. In this task, participants were presented with three sequential images. Each image contained one bar that was placed just above two other bars. Each bar image was displayed for 800 milliseconds and there was a 400 millisecond blank image between each bar image.

When each bar image was presented, participants had to decide if the top bar was able to fit between the lower two bars, pressing the appropriate key on the keyboard – ‘q’ for no fit and ‘p’ for fit’.

The bar fit task has been suggested to inhibit the use of visual and spatial domain specific resources and therefore inhibits the rehearsal of any visual information within the visual working memory components such as the Visual Cache or VSSP (Vergauwe et al., 2009). Please see Figure 5.2. for an example of this task.

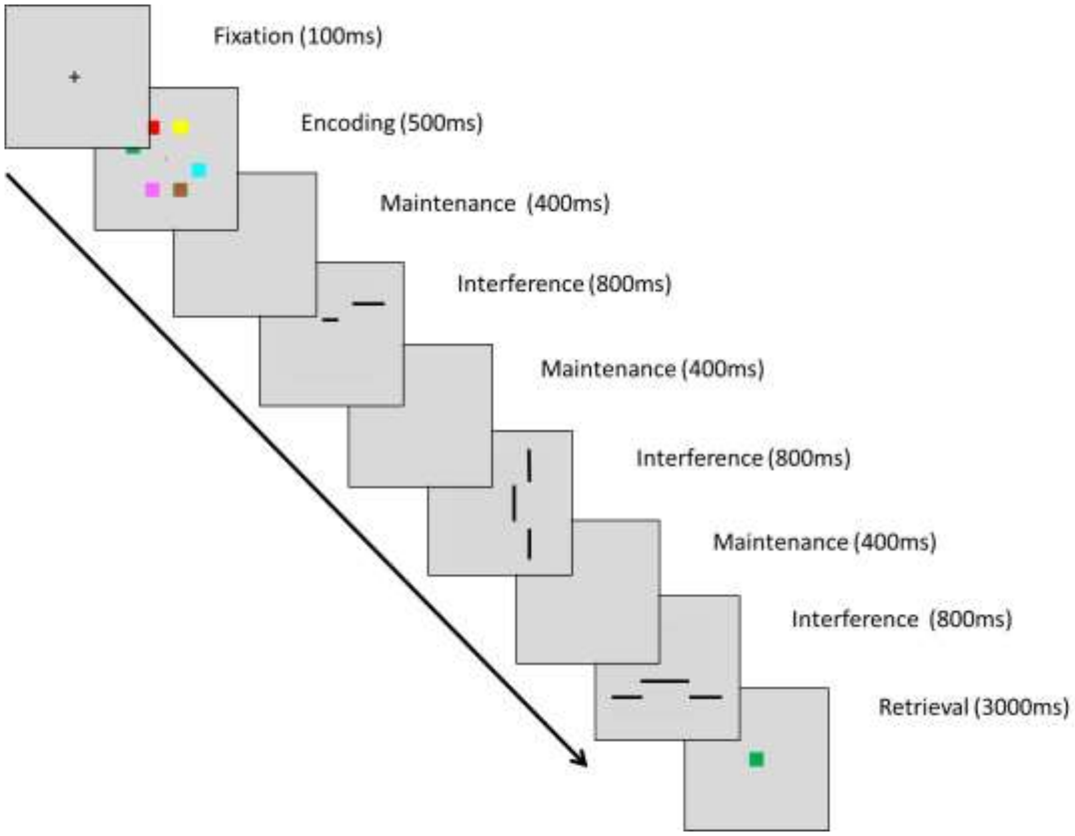

Figure 5.2. An example of a quantitative task trial including visual attention interference.

5.5.3.3 Secondary Task, Verbal Attention – Verbal Parity Task

A verbal attention task (Verbal Parity Task) was presented in the 4000 millisecond maintenance interval. Each number was verbally displayed for 800 milliseconds and there was a 400 millisecond blank interval between each number. In this task, participants listened to three sequential numbers and had to decide if each one was odd or even, pressing the appropriate key on the keyboard – ‘q’ for odd and ‘p’ for even,

The verbal parity task has been suggested to use and inhibit phonological domain specific resources (Lépine et al., 2005) and prevents the rehearsal of verbal information in the

Phonological Loop within working memory. It has also been suggested that tasks such as this can use general attention executive resources (Brown and Wesley, 2013). Please see Figure 5.3. for an example of this task.

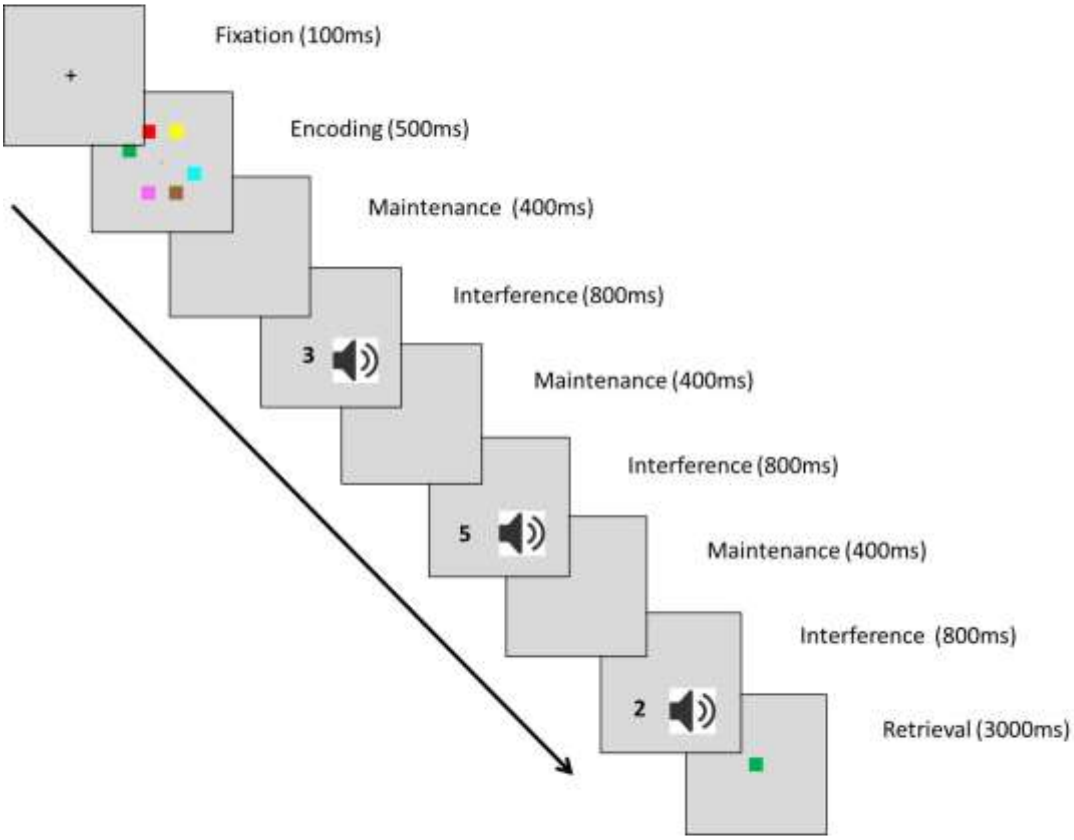

Figure 5.3. An example of a quantitative task trial including the verbal attention interference.

5.5.4 Overall Procedure

The current investigation was ethically approved by the University Health and Life Sciences Ethics Committee. An information sheet and a consent form were given to participants at the start of the investigation. As there were 12 different components to this experiment, all task orders and instruction sheets were randomised for each participant to reduce fatigue effects and practice effects. Please see appendix G for an example of the task order.

The total testing session lasted one hour. Each task was fully explained to participants using visual diagrams before the testing phase began.

Participants were guided through the experiment and were given the appropriate instruction sheet or task. Participants were asked to work through the task and inform the researcher upon completion so that the programme could be changed to the next one. Once all tasks had been competed, participants were fully debriefed, thanked for their time and were reminded of their right to withdraw.

5.5.5 Scoring of all tasks

Participants were awarded 1 point for a correct change detected and 0 points for an incorrect response and all tasks could have a maximum of 20.

Within the dual task paradigm, the verbal and visuospatial attention tasks totalled 60 due to the three different memory probes in each trial. In this case, averages were taken of the three memory probes and averages again could have the highest score of 20. This allowed researchers to compare the results of both primary and secondary tasks using a similar measurement of working memory capacity (out of 20).

5.6 Results

5.6.1 Raw Data

Any baseline data which was above or below the 70-90% performance level was not included in the analysis. This was to eliminate any possibility of floor or ceiling performances. Due to this reason, only 11 participants' data was used in the analysis as 8 data sets had to be disregarded.

Table 5.1. Means and Standard Deviations of the raw scores of the primary change detection task in each interference condition.

	Baseline	Visuospatial (Bar Fit)	Verbal (Verbal Parity)
Array Size 4	17.81(1.53)	14.81(2.71)	15.09(2.84)
Array Size 6	14.63(1.43)	13.63(3.04)	12.27(2.76)

Table Notes:

As the raw data does not consider the cost of completing two tasks at the same time, Mu scores were used throughout the analysis as Mu scores consider the performance and cognitive demand cost of a dual task context.

Post Hoc Analyses

Where post hoc analyses were needed for a main effect given from an ANOVA, the Bonferonni function within the ANOVA SPSS analysis was used which automatically adjusts the alpha level accordingly. When following up an interaction effect, this Bonferroni function was not used and instead, paired smaples t-tests were conducted with the appropriately adjusted p values for each correction (for example, alpha/number of hypotheses tested).

5.6.2 Mu Score Calculations

Mu scores were calculated for the change detection task conditions which included visuospatial (bar fit) and verbal (verbal parity) interference. Mu scores take into consideration the cost of using a dual task paradigm and directing attention to both tasks in a short space of time. Orme (2009) used an adapted formula of Baddeley, Della Sala, Papagno and Spinnler (1997) as shown in Figure 5.4.

$$mu = \left[\frac{\left(\frac{ps - pd}{ps}\right) + \left(\frac{ss - sd}{ss}\right)}{2}\right] \times 100$$

ps = primary task score, single procedure

pd = primary task score, dual procedure

ss = secondary task score, single procedure

sd = secondary task score, dual procedure

Figure 5.4. The formula used to calculate the Mu scores for the visuospatial and verbal interference conditions. These were taken from Orme (2009).

Table 5.2. Means and standard deviations of the Mu scores calculated using the above formula.

	Visuospatial Mu	Verbal Mu
Array Size 4	83.23 (14.44)	87.29 (7.06)
Array Size 6	94.04(22.52)	86.86(5.38)

Table Notes: *Visuospatial = bar fit task, Verbal = verbal parity task

A 2(interference type) x 2(array size) repeated measures ANOVA was conducted on the Mu scores. No significant main effects of set size were found $F(1,10)= 1.724$, $p=.218$ partial $\eta^2 = .147$. There was no significant main effect of interference type $F(1,10)= .110$, $p=.747$, partial $\eta^2 = .011$. No interaction effects were present between array size and interference type, $F(1,10)= 2.880$, $p=.121$, partial $\eta^2 = .224$.

5.6.3 T-tests On Mu Scores

One samples t-test were conducted to show any differences the Mu scores were from the mean of 100. The Mu score for the visuospatial and verbal interference in array size 4 were significantly different from 100, with array size 4 visual interference having an average of 83.23 (SD=14.44), $t(10) = -3.849$, $p = .003$, and the verbal interference having an average of 87.29 (SD=7.06), $t(10) = -5.965$, $p = .<.001$. For array size 6, only the verbal interference was significantly different from 100, showing an average of 86.86 (SD=5.38), $t(10) = -8.085$, $p < .001$. These three results indicated interference effects from the visual and verbal interference types at array size 4 and also the verbal interference at array size 6. Please see Table 5.3. for the effect sizes associated with the Mu analyses.

Table 5.3. Quantitative (Mu) interference effect sizes.

	Visuospatial Mu	Verbal Mu
Array Size 4	$d = 0.852$	$d = 1.600$
Array Size 6	$d = 0.193$	$d = 1.694$

Table Notes:

The effect sizes, presented in Table 5.3. demonstrate larger effects with the verbal interference at both array sizes compared to the visuospatial interference effect sizes. This supports the findings of the Mu analyses and suggests a larger verbal interference effect.

5.7 Discussion

The aim of this investigation was to look at the functional working memory architecture of a quantitative change detection task to see if visual and verbal semantic representations mediated by executive attentional demands, were at use. This was completed by using a dual task procedure context, incorporating two interference paradigms (verbal parity and bar fit task) with the primary task, the Luck and Vogel (1997) quantitative change detection protocol. The visuospatial attention task had a significant effect of array size 4 but not array size 6. The verbal attention task was found to have a significant effect of array size 4 and also array size 6. Prediction 1, suggesting that the visuospatial interference would have an effect, was supported. However, prediction 2 was not. Prediction 2 proposed that the verbal interference would have no effect, however this was found to not be the case and interference effects were present.

The visuospatial attention task (bar fit task) was shown to interfere with array size 4, however not array size 6. One potential reason for this could be due to the fact that array size 6 is above the capacity limit of 3-4 items as Luck and Vogel (1997) suggested. This could mean that all 6 items were not fully encoded and therefore were not susceptible to interference. One other reason could be an added verbal resource use at array size 6. As array size 4 can be rapidly encoded within working memory with it being within the capacity limit of 3-4 items (Luck and Vogel, 1997), when array size 6 is presented, participants may need to find another way of representing all 6 items in working memory if the visual resources have been at use for array size 4. The visual resources may have been fully used at array size 4; meaning additional (verbal) resources may have been needed for array size 6, making this array size less visual in nature.

The current interference results do show support for the multicomponent approach of Vergauwe et al. (2009). Here, researchers demonstrated the bar fit task to interfere with the memory of matrix patterns, similar to that of the current results finding interference effects with the quantitative change detection task. As the bar fit in the current investigation task demonstrated interference with array size 4, the quantitative change detection task can be shown to make use of visual resources with coloured stimuli but it can also be questioned as to whether the quantitative change detection task also has spatial elements to it. As the bar fit task did interfere with the change detection task, it can be questioned as to whether both visual and spatial representations were being used as in the research of Vergauwe et al. (2009). This suggestion of both visual and spatial material use could potentially mean that the change detection task is not as purely visual as first thought by Luck and Vogel (1997), with interference being presented from the verbal attention interference task also, and further investigations may be needed to look further at the implication of spatial working memory. To investigate further a spatial tapping task (Brown and Wesley, 2013) could be implemented, as this has a greater impact on the spatial specific components such as the Inner Scribe. This would make the visual/spatial distinction of interference effects more clear and would give a distinct indication of whether the Inner Scribe is also being used during the completion of the task.

The results of the verbal attention interference condition (verbal parity task) do suggest that verbal representations can be used during a visual change detection task, similar to that shown by Brown and Wesley (2013). Brown and Wesley (2013) had investigated the use of verbal semantics upon the visual patterns test, and this lead to the question regarding the current change detection paradigms. As shown in the current experiment, it can be suggested that verbal semantics may contribute to the representations of the information within working memory. The current investigation demonstrated verbal interference of array size 4 and array size 6, suggesting that a verbal, executive or amodal resource could be at use during both smaller and larger array sizes. The verbal resources could be used as a way of supporting the visual resources, if the visual resources have already been used. As the current experiment did not use articulatory suppression, due to this being less demanding compared to the verbal parity task, the interference effects can suggest that the Phonological Loop alone was not at use here. As both visual and verbal information was potentially being used by the change detection task, a component such as the Episodic Buffer could be at use to integrate the use of visual, verbal and spatial information.

Results also support perspectives from other researchers who have suggested that an executive resource could be at use during visual tasks (Hamilton et al., 2003). Hamilton et al. (2003) investigated the visual-spatial distinction within working memory and suggested the potential use of an executive resource to integrate the different types information within memory. A similar explanation could be given for the current investigation, suggesting an executive resource use to integrate the visual and verbal information within a change detection task. However, the current research has not clearly made reference to the extent to which these potential executive resources are at use within the task. Using a more executive interference task as Brown and Wesley (2013) did such as random tapping would give an indication of the strength of any executive processes as use. Rudkin et al. (2007) also found executive involvement within a visual memory task. However, unlike the current investigation, the work of Rudkin et al. (2007) used a matrix task. The current research has extended these findings of Rudkin et al. (2007) and has potentially found executive resource use within a different type of task – a quantitative change detection task.

The findings from the current study most importantly contradict research by Luck and Vogel (2013) who suggested that visual memory tasks should use visual representations only. It was demonstrated that this may not be the case, specifically for a colour change detection task. Luck and Vogel (2013) used the model created by Baddeley (2012) to suggest that information is stored directly into the VSSP on a perceptual level, with no influence of semantic or verbal representation use. The current results have demonstrated that this may not be the case and supports the previous research of Hamilton et al. (2003) and Brown and Wesley (2013). As the verbal parity task affected the performance levels of the change detection task for both array size 4 and 6, it can suggest that either a Phonological Loop component is at use, or an Episodic Buffer is at use to assist with the incorporation of verbal semantics or within the suggested visual task.

Results can also be said to contradict the work of Shah and Miyake (1996) who proposed a domain specific approach to working memory with regards to verbal and spatial tasks. The current investigation demonstrated cross-domain interference (verbal interference in a visual memory task) meaning that there may not be two distinct memory systems as proposed by Shah and Miyake (1996). Instead, a more domain specific approach can be adopted, whereby a visual task may use verbal any spatial types of information.

At present, it can therefore be concluded that the model suggested by Logie (2011) is the most appropriate to use with regards to a quantitative change detection task. The current investigation has demonstrated the potential influence of semantics (or verbal information) and potentially an Episodic Buffer component. From this is can be proposed that the objects are stored at an 'object' level to allow the incorporation of verbal semantics. As the current investigation showed no visual specific interference from the Bar Fit Task only, this domain specific models from Baddeley (2012) and Luck and Vogel (2013) can be disregarded as an explanation of results and a multicomponent approach can be adopted.

Improvements and Future Research

One limitation of the current research could be the lack of defining how a component such as the Central Executive component could contribute to the working memory architecture of the quantitative change detection task. Although the aim of the current research was to discover if verbal representations were present with the use of the more verbal components such as the Phonological Loop or the Episodic Buffer, the current research did not look at how a component such as the Central Executive could contribute to the completion of the tasks.

To investigate this further, future research could suggest the use of a more executive interference paradigm such as that of Brown and Wesley (2013). Brown and Wesley used a random tapping task where participants would tap a board at random intervals to demonstrate the effects of a central executive task. The current research demonstrated the use of both visual and verbal information during the current change detection task, and an extension of this research could investigate the contributions of the Central Executive to the working memory architecture of the quantitative change detection task. This however, would mean reconsidering models such as Baddeley's recent account which uses a Central Executive component as a control system for each of the slave systems.

Researchers noted that the verbal interference paradigm, the verbal parity task (taken from Lépine et al., 2005), may have also involved spatial elements within the task, essentially making this task not purely verbal. As participants had to press a key to respond, coordination between verbal, visual and spatial elements was needed. In future, it may be an idea to use a purely verbal interference task such as articulatory suppression as used by Baddeley, Lewis and Valler (1984) where either numbers or letters are repeated for the duration of the task to inhibit any Phonological Loop rehearsal. This could cause disruption to the Phonological Loop without the potential disruption of the visuospatial components.

5.8 Chapter Summary

This chapter has detailed the third study of the doctoral thesis which enabled researchers to establish whether the quantitative visual change detection task uses purely visual representations or whether there are forms of semantic and verbal contributions. A more multicomponent theoretical approach can be used due to finding the influence of semantics and potential verbal representations, indicated from both visuospatial and verbal interference tasks.

It can now be questioned as to whether coordinate (qualitative) changes in stimuli can be discussed in a similar way and whether verbal semantic can also influence the working memory of small changes in visual arrays. The next chapter, chapter 6, will investigate the qualitative visual working memory task using the same dual task paradigm to make a comparison between the two types of visual change detection tasks.

CHAPTER 6

Qualitative Interference Study 4a and 4b

6.1 6.1. Chapter Overview

Chapter 5 looked at the representations used within a quantitative change detection task, finding that this task can use both visual and verbal information. There were large effects associated with both visual attentional and verbal attentional task interference. In this study the verbal interference, as considered by the Mu effect, had a significantly greater impact. This lead to the assumption that quantitative change detection tasks may not be as visual specific as suggested by Luck and Vogel (2013), but is more consistent with a view that visual working memory tasks may demand both domain specific and domain general cognitive resources (Brown & Wesley, 2013; Hamilton et al., 2003; Shipstead & Yonehiro, 2016). The current chapter gives an overview of study 4 of the current doctoral thesis which uses the same dual task context for a qualitative change detection task in order to identify whether a similar pattern of results occur with regards to the type of cognitive resource demanded in the change detection protocol. In this chapter, it will be questioned as to whether the qualitative change detection task uses verbal semantic representations as previously suggested by the literature (Brown & Wesley, 2013; Hamilton et al., 2003; Shipstead &Yonehiro, 2016). Discussions regarding this task will include the two general working memory models by Logie (2011) and Baddeley (2012) and comparisons will be made to the working memory functional architecture of the quantitative change detection task in chapter 5.

6.2 Background

Chapter 5 discussed in detail the use of verbal semantic information within a quantitative change detection task, making the suggestion that not all visual tasks are visual specific in nature (Logie, 2011). Previous researchers such as Brown and Wesley (2013) and Hamilton et al. (2003) have identified that a visual task may make use of verbal semantics or an Episodic Buffer like process to allow the use of both visual and verbal components within the working memory functional architecture of a visual memory task. In line with study 3 of the current doctoral thesis, study 4 will aim to use a dual task procedure to identify whether a contrasting qualitative change detection task also uses verbal representations with the suggestion of an Episodic Buffer component within the working memory architecture of the task. Please see the background section of chapter 3 for further details on these procedures.

6.3 Rationale for Study 4

The current study will be using a task which contrasts the Discrete Slot Model (Luck and Vogel, 1997). The qualitative change detection task is based upon the Shared Resource Model of working memory capacity (Bays et al., 2009) which focuses upon working memory resource demands in terms of the precision or fidelity of the fine details of the stored representations. The previous study (study 3, chapter 5) focussed upon the representations within a quantitative colour change detection task; therefore, the current study will expand on this and will look at the alternative qualitative size change detection task. This task focuses upon high resolution in visual memory such as the size of a shape as discussed by Bae and Flombaum (2013). Similar dual task methods to study 3 will be used, and only the primary task will be changed so that the results of study 3 and 4 can be compared. The two interference paradigms that will be used are: a bar fit task (Vergauwe et al., 2009) and a verbal parity task (Lépine et al., 2005). Each task is designed to target a specific component within the working memory functional architecture. Please see the methodology section of chapter 5 for these details.

6.4 Prediction of study 4

1. The verbal attention task will interfere with the qualitative size change detection task, suggestion a domain general or multicomponent resource at use and therefore supporting the work of Logie (2011).
2. The visuospatial interference task will have a larger effect upon the qualitative change detection task, indicting the greater use of visual representations.

6.5 Method

The method of this experiment was similar to that of experiment 3, however instead of coloured square arrays as the primary stimuli, different sized shape arrays were given to participants as the primary qualitative change detection task. This task was piloted in chapter 4 of the current doctoral thesis.

6.5.1 Design

A 3 x 2 repeated measures design was used for the purposes of this experiment. Factor 1 was the interference type – baseline, visuospatial interference and verbal interference. Factor 2 was the array size consisting of either 1 or 2 shapes.

6.5.2 Participants

4b: 11 participants (all female with a mean age of 21 and a standard deviation of 3.13) took part in the investigation. Participants were from the area of Newcastle-upon-Tyne and those who were Undergraduate Psychology student received 4 points of course credit for their participation. Participants had no conditions such as photosensitive epilepsy which could be triggered by the tasks in the investigation.

6.5.3 Materials

Materials were very similar to that of study 2. A Verbal Parity task was used as the verbal interference and a Bar Fit task was used as the visuospatial interference. Please see chapter 5 for further details of these tasks.

There were three main changes to the method of study 4 (compared to study 3) and these are detailed below. In all tasks, 24 trials were used instead of the 20 used by the quantitative change detection task. This was to ensure that all percentage changes were used. Please see the methodology section of chapter 5 for an explanation of the three interference paradigms.

6.5.3.1 Methods Change 1: the primary task was different.

Primary Change Detection Task

Array sizes 1 and 2 were used from the previous experiment in chapter 4 (experiment 2). Central location retrieval arrays were used for the purpose of this experiment to ensure this was the same as the quantitative change detection task.

Each encoding array consisted of either 1 or 2 shapes (square, circle or triangle). The retrieval array consisted of one centrally presented shape. There were varying changes consisting of 5%, 10%, 15% or 20%, reductions or enlargements in the retrieval array stimuli.

Each primary e-prime task consisted of only 24 trials. In each task there were 10 trials consisting of 5% size changes, 8 images consisting of 10% size changes, 4 trials consisting of 15% size and 2 trials consisting of 20% size changes. In each trial, the encoding array was presented for 500 milliseconds, followed by a maintenance array for either 900 milliseconds (practice) or 4000 milliseconds (interference task). Finally, a retrieval array was presented for 3000 milliseconds, where the participant had to indicate whether the probe stimulus was now larger or smaller than the congruent stimulus in the memory array. Please see Figure 6.1. for an example of 1 trial.

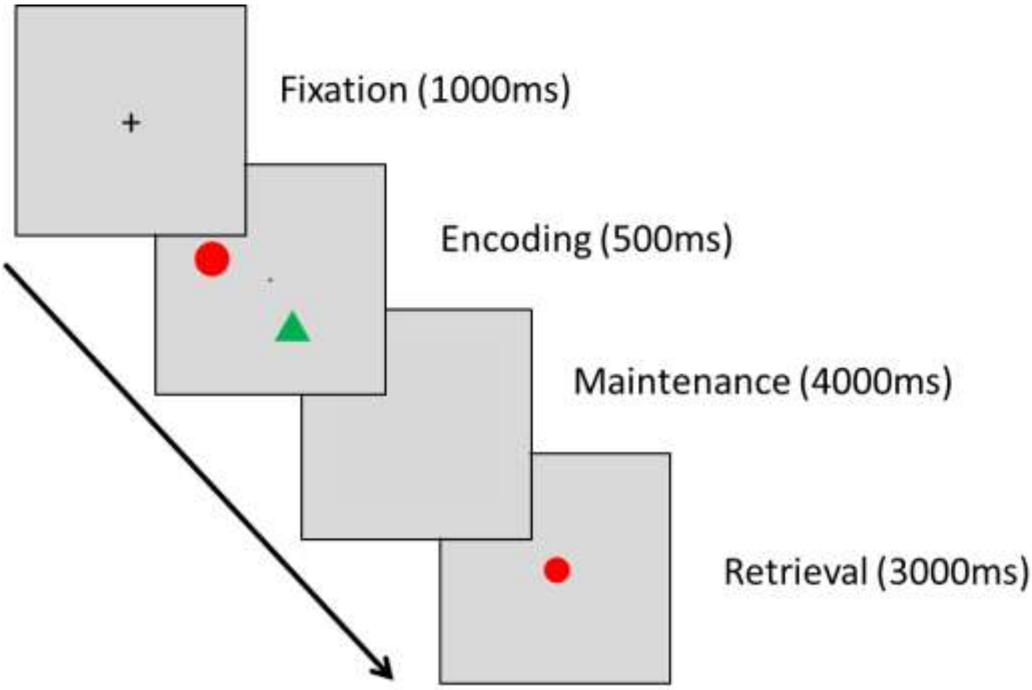

Figure 6.1. An example of one trial containing the shape stimuli.

6.5.3.2 Methods Change 2: adaptation of secondary tasks

The initial running at this qualitative interference study evidenced a 90-100% ceiling performance levels of the Bar Fit task and the Verbal Parity task in participant performance, therefore analyses were not conducted using the data from study 4a.

As a result of this, the secondary task demands were modified in this study. Both the Verbal Parity task and Bar Fit task were changed and made more demanding by adding in an additional secondary task item per trial during the maintenance interval, enabling the task to be more difficult for participants. The results of the new attempt at study 4 (named 4b) are detailed below in the next section.

Visuospatial Attention – Bar Fit Task Adaptation

The Bar Fit task was adapted to make the task more demanding. Instead of having 3 items per trial (please see Figure 5.2. in Chapter 5 for an example), an extra item was added so that 4 items were included in each trial. The bar images were still displayed for 800 milliseconds, however, the blank interval between each image was reduced to 100 milliseconds to encourage a quicker response from participants.

Verbal Attention – Parity Task Adaptation

The Parity task was adapted to make the task more demanding. Instead of having 3 items per trial (please see Figure 5.3. in Chapter 5 for an example), an extra item was added so that 4 items were included in each trial. The verbal numbers were still presented for 800 milliseconds, however, the blank interval between each image was reduced to 100 milliseconds to encourage a quicker response from participants.

6.5.4 Procedure

The procedure was very similar to that of study 3 (chapter 5) except the use of the primary qualitative change detection task.

The current investigation was ethically approved by the University Health and Life Sciences Ethics Committee. Information sheets and consent forms were given to all participants before any tasks were explained. As there were 14 different components to this experiment, all task orders and instruction sheets were randomised for each participant to reduce fatigue effects and practice effects. Please see Appendix G for an example of the task order for participants.

Each task was fully explained to participants before the testing phase began. Please see Appendices B, D and E for examples of instruction sheets.

Participants were guided through the experiment and were given the appropriate instruction sheet or task. Participants were asked to work through the task and inform the researcher upon completion. Participants were fully debriefed at the end of the investigation and were reminded of how they could withdraw. The total testing session lasted one hour.

6.5.5 Scoring of all tasks

Scoring was similar to that of study 3. Initially total correct scores were taken for each task. Each separate programme had a total score of 24. These were converted into performance levels by changing the scores into percentages. The visual and verbal interference tasks consisted of 94 items for experiment 4b (4 items per trial of visuospatial and verbal interference). The total scores on each trial were averaged so that a score out of 24 was obtained.

6.6 Results

6.6.1 Raw Data

Any baseline data which was above or below the 70-90% performance level was not included in the analysis. This was to eliminate any possibility of floor or ceiling performances. In this case, no participant's data was removed.

Table 6.1. Means and standard deviations of the raw scores of the primary change detection task in each interference condition.

	Baseline	Visuospatial (Bar Fit)	Verbal (Verbal Parity)
Array Size 1	17.7(3.02)	18.5(2.99)	15.50(2.75)
Array Size 2	19.30(1.15)	19.20(2.25)	17.10(3.24)

Table Notes: each condition could have a maximum score of 24.

As the raw data does not consider the cost of completing two tasks at the same time, Mu scores were used throughout the analysis as Mu scores consider the performance and cognitive demand cost of a dual task context.

Post Hoc Analyses

Where post hoc analyses were needed for a main effect given from an ANOVA, the Bonferonni function within the ANOVA SPSS analysis was used which automatically adjusts the alpha level accordingly. When following up an interaction effect, this Bonferroni function was not used and instead, paired smaples t-tests were conducted with the appropriately adjusted p values for each correction (for example, alpha/number of hypotheses tested).

6.6.2 Mu Score Calculations

Mu scores were calculated for the change detection task which included visuospatial and verbal interference. Mu scores take into consideration the cost of using a dual task paradigm. Orme (2009) used an adapted formula of Baddeley, Della Sala, Papagno and Spinnler (1997). Please see the results section in chapter 5 for the Mu score formula.

Table 6.2. Means and standard deviations of the Mu scores calculated using the formula from Chapter 5.

	Visuospatial Mu	Verbal Mu
Array Size 1	105.80(19.84)	88.70(12.41)
Array Size 2	101.90(8.56)	. 92.10(13.77)

Table Notes: *Visuospatial = bar fit task, Verbal = verbal parity task

A 2(interference type) x 2(set size) repeated measures ANOVA was conducted on the Mu scores. There was no significant main effect of array size found $F(1,9)= .008, p=.929$, *partial* $\eta^2 = .001$. There was a significant main effect of interference type with the verbal interference showing a lower Mu score (90.40, SD=13.09) than the visuospatial Mu (103.85, SD=14.20)), $F(1,9)= 6.259, p=.034$, *partial* $\eta^2 = .410$. There was no interaction effect found between set size and interference type $F(1,9)=1.667, p=.308$, *partial* $\eta^2 = .15$.

6.6.3 T-tests on Mu Scores

One sample t-tests were conducted to compare the visuospatial and verbal interference to the mean performance level of 1 (100%), similar to that of the previous chapter (chapter 5).

Only the verbal interference for array size 1 demonstrated a significant effect of verbal interference, $t(9)= -2.804, p =.021$. This supports the analysis above which demonstrated that the verbal interference had a larger effect (as evidenced by the Mu measure) than the visual interference which was demonstrated to be non-significant. No other interference types were significant (all ps>.05). An additional measure was also taken which looked at the combined memory and interference task proportion correct at both baseline and during the dual task context. This enabled the underlying effect sizes of mu changes to be calculated for the visuospatial and verbal interference protocols. Table 6.3. below, indicates, the effect sizes associated with array size and modality of interference.

Table 6.3. Qualitative (Mu) interference effect sizes.

	Visuospatial Mu	Verbal Mu
Array Size 1	*d = -0.330*	*d = 1.129*
Array Size 2	*d = -0.199*	*d = 0.765*

Table Notes: *Visuospatial = bar fit task, Verbal = verbal parity task

The table demonstrates clearly that across both array sizes a larger effect size was associated with verbal interference.

6.7 Initial Discussion

The main aim of the current investigation was to look at the working memory architecture of the qualitative change detection task, using similar dual task methods to that of the quantitative change detection task from study 3. This was to discover whether both visual and verbal information types were being used during this task and to discover if a more multicomponent approach could be taken towards these tasks as proposed by Logie (2011), as opposed to the original visual specific approach (Baddeley, 2012).

The current investigation also aimed to change the visuospatial and verbal attention tasks which were used in study 4a so that they were seen as more task demanding for participants. Instead of showing 3 bars per trial or 3 numbers per trial, this was increased to 4 to eliminate the ceiling effect present in study 4a. There were 2 predictions regarding this study, stating that 1) the verbal interference task would have an effect on the primary task and 2) the visuospatial interference task would have a greater effect upon the change detection task indicating the greater use of visual representations. Results have supported prediction 1 but not prediction 2 as results demonstrated verbal interference but no visuospatial interference effects.

The effect of verbal interference in the current qualitative change detection task gives support to the previous literature from Brown and Wesley (2013) and also Hamilton et al. (2003). Here, researchers demonstrated a more multicomponent approach to working memory architecture with interference effects from executive interference procedures such as random tapping.

Brown and Wesley (2013) produced results which indicated that a VPT can indeed use verbal representations, and the current study provided evidence for this using a qualitative stimuli paradigm. The findings of Brown and Wesley (2013) have been extended by the current results showing that a qualitative change detection task may also use domain general resources. Although Brown and Wesley (2013) and the current study used different methods in regards to the different interference procedures used, the evidence provided can still support the theoretical implications which implicate a more multicomponent approach (Logie, 2011).

The current results have contrasted the visual specific research from Luck and Vogel (1997, 2013). Luck and Vogel (2013) had proposed in their research review that visual working memory tasks should use visual material only and stated that if a visual memory task uses any type of other (verbal, amodal) representation then this task could not be seen as a visual working memory task. The current investigation has opposed the view of Luck and Vogel (2013) by providing evidence for the effect of verbal interference, suggesting the use of verbal information in a visual task as well as potentially visual information.

The findings that the Bar Fit task had no effect upon the qualitative stimuli has contradicted that of Vergauwe et al. (2009) who initially used the Bar Fit task to demonstrate that a visual matrix task could use visual and spatial elements. Vergauwe et al. (2009) used a maintenance interval of 8500ms which was more than double of the current study. It could be suggested that the longer maintenance interval may contribute to the decline in memory as well as the visual interference paradigm. In the preliminary study by Vergauwe et al. (2009) several data sets were not used in the analysis as they did not approach the 80% performance level suggested for maximum task demands. This was a similar case with the current thesis for study 3 and 4b. Current researchers chose a 70-90% performance level interval and any data which did not meet this criterion was excluded from the analysis to ensure that the interference tasks were demanding enough as Vergauwe et al. (2009) suggested. This reduced great variability within the data sets and ensured that each task used the appropriate level of difficulty.

The interference of the Verbal Parity task in the current investigation has provided support for the suggestion that this task can interference with any form of task (Lépine et al., 2005). Lépine et al. (2005) proposed that a verbal task may affect any form of other task, based upon the fact that it causes a divide in attention between the primary and secondary task. It was suggested that a distraction in attention from the primary task was enough to cause effects upon a primary task as interference effects were concerned with a person's attentional control ability and not the fact that the secondary task was supposed to hit a specific working memory component.

Conclusions can be made suggesting that a more multicomponent approach could be used to discuss the working memory architecture during qualitative working memory tasks (Logie, 2011). The interference from the verbal interference task demonstrated the use of verbal representations, or potentially an executive resource function (Brown & Wesley, 2013) that could integrate both visual and verbal information in memory.

One question remains regarding the effects of the verbal interference. Although these interference types were seen to have an effect upon the qualitative change detection task, it is unclear as to where these interferences are hitting. As the qualitative task used both smaller 5-10% changes and larger 15-20% changes, it raises questions as to where exactly this interference was hitting. In the next section, further analyses will now be conducted to look at the specific location of the interference types.

6.8 Section Summary

The current chapter began with the implementation of the qualitative dual task paradigm and found that participants were performing at approximately 90% ceiling level, therefore interference tasks were made to be more demanding in a second attempt at study 4. As a result, the visuospatial and verbal interference tasks were made more difficult be adding in an extra item per trial to complete. A small change of adding one more item into the interference task made the two interference tasks more difficult and allowed the performance levels to fall in the 70-90% performance level range as suggested by Vergauwe et al. (2009) and Lépine et al. (2005).

Results showed a verbal interference effect within the qualitative change detection task; however, a question was raised regarding the location of these effects. Are these interference types hitting the smaller or larger changes in visual arrays? The next section of this chapter can help to answer this question by running an analysis which compares the smaller 5-10% changes to the larger 15-20% change interference effects.

6.9 Percentage Change Analysis

For the purposes of the percentage change analysis, the raw data was re-ordered and categorised into two groups. The ‘small’ group contained size changes that were either 5% or 10% and the ‘large’ group contained size changes that were either 15% or 20%. This enabled a comparison between the small and large stimuli. Error rates were then calculated for each condition using the percentage of 'incorrect' responses (1 = 100% errors, 0= no errors).

In this section, 4b will be analysed to discover if any interference effects were apparent in the set of data.

6.9.1 Individual ANOVAS on each percentage change

In order to look at the effect of interference on the qualitative task when small (5%, 10%) and large (15%, 20%) changes occurred, a 3 way ANOVA, 2 (Interference) x 2 (Array Size) x 2 (Change Size), was carried out within each of the visuospatial and verbal interference contexts. Table 6.4., below, shows the error rates associated with the interference conditions.

Table 6.4. Means and standard errors of the error rates associated with the interference types.

	Baseline		Bar Fit		Verbal Parity	
	Small	Large	Small	Large	Small	Large
Array Size 1	.29(.13)	.13(.13)	.25(.12)	.17(.16)	.35(.14)	.33(.01)
Array Size 2	.24(.07)	.07(.12)	.24(.10)	.15(.14)	.31(.14)	.23(.21)

Table Notes:

<u>Visuospatial (Bar Fit) Interference</u>

The 3-way repeated measures ANOVA revealed no significant effect of interference *$F(1,9)$= 0.207, p=.660, partial η^2 = .022.* No significant main effects of array size was also found *$F(1,9)$= 2.674, p=.136, partial η^2 = .229.* However, a highly significant main effect was associated with change size was found*, $F(1,9)$= 30.766, p<.001, partial η^2 = .774.* As anticipated, error rate was substantially higher for the small 5%, 10% (overall mean = .257, SD = .11) compared to the larger, changes (overall mean = .129, SD = .15). No significant interactions were found (all ps > 0.100).

Verbal (Parity) Interference

The 3-way repeated measures ANOVA revealed a significant effect of interference $F(1,9)= 9.221, p=.014, \text{partial } \eta^2 = .506,$ a marginally non-significant main effects of array size was found $F(1,9)= 4.730, p=.058, \text{partial } \eta^2 = .344.$ A highly significant main effect was associated with change size, $F(1,9)= 22.182, p<.001, \text{partial } \eta^2 = .711.$ As anticipated, error rate was substantially higher for the small 5%, 10%, changes (overall mean = .298, SD = .14) compared to the larger changes (overall mean = .192). Importantly, there was one significant interaction, Interference * Change size, $F(1,9)= 6.683, p=.029, \text{partial } \eta^2 = .426$. The nature of this interaction is shown below for array sizes 1 and 2 in Figures 6.2. and 6.3. No other significant interactions were found (all ps > 0.5).

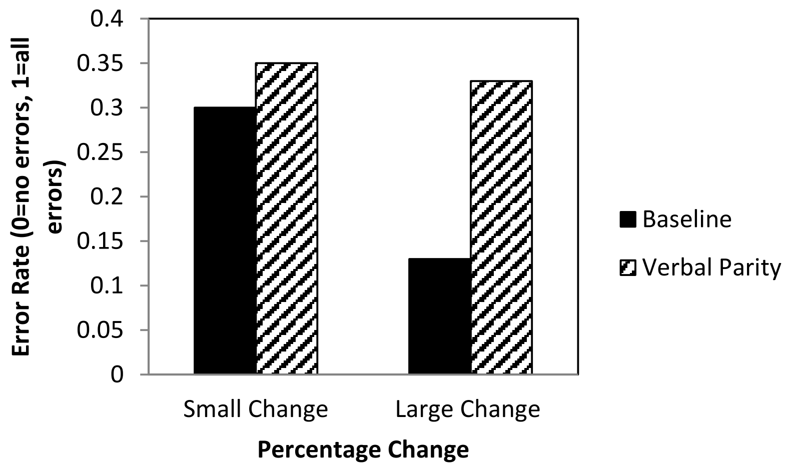

Figure 6.2. Effect of verbal parity interference upon small and large change sizes in array size 1.

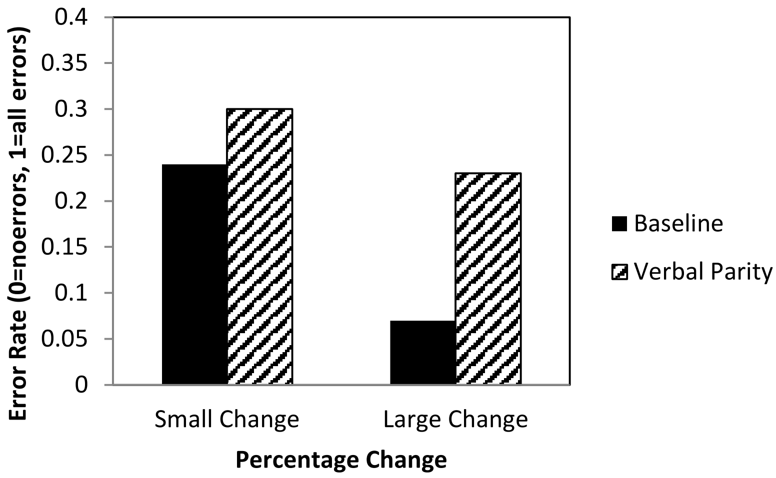

Figure 6.3. Effect of verbal parity interference upon small and large change sizes in array size 2.

The figures (above) indicate that the source of the interaction between Interference and Percentage Change Size is in the relatively larger effect of verbal parity interference in the larger change size trials.

Paired samples t-tests were conducted on the data for each array size. For array size 1, there were no significant differences between the interference types of the small changes, *t(9) = -.705, p=499*, however there was a significant difference between the interference type of the large changes, *t(9) = -4.788, p=.001*. The interaction effect appears to be coming from the higher error rates with the verbal interference (M =.33, SD = .01) compared to the mean baseline error rate of .13 (SD=.13).

Similar findings were presented for array size 2 with no significant interference differences presented within the smaller changes, *t(9) = -1.424, p=.118*. Similar to array size 1, array size 2 presented verbal interference effects with the larger changes as the verbal interference condition had significantly higher error rates (M = .23, SD=.21) to that of the baseline condition (M =.07, SD=.12), *t(9) = -2.539, p=.032*. Please see figures 6.2. and 6.3. for a graphical representation of this interaction. Separating the data into two interaction graphs has demonstrated that the interactions were similar across array sizes 1 and 2, indicating no three-way interaction effect.

6.10 Discussion of Percentage Change Analysis

The main aim of this final analysis for study 4b was to split the data into small changes of 5% and 10%, and also large changes of 15% and 20% to look at any differences in the interference effects of the small and large change stimuli.

An initial analysis revealed that the small changes had higher error rates which demonstrated that the 5% and 10% changes were more difficult to detect that the 15% and 20% changes. Significant interactions were presented in this study, and of particular interest, were the interactions between the size of the change and the interference type in the verbal interference context. Figures 6.2. and 6.3., above indicate that the source of the interaction effect is that the verbal parity task is only interfering with the large change trials in the qualitative change detection protocol. This suggests that where a verbal semantic label is able to be employed effectively with the large change trials then verbal interference will affect performance. However, such a label is ineffective with the smaller change trials, and thus is not effective; consequently, verbal interference has little effect upon these trial performances.

It was also demonstrated that neither the visuospatial interference task nor the verbal parity task had any effect upon the smaller changes, which was not expected, therefore leading to the conclusion that this type of change detection task, with small size changes requiring high resolution or fidelity, may not be affected by attentional interference of the type employed in this study. Future investigations, whereby only small changes are used, with other attention interferences protocols may give a clearer indication of which type (if any) of interference (visuospatial, verbal or generic domain general attention) the fine change qualitative task may be susceptible to.

Improvements and Future Research

Limitations of the current study can be discussed in terms of the interference paradigms used and also the division of the small and large size changes in the stimuli.

In line with the quantitative change detection dual task, the current investigation used the two interference paradigms of a Bar Fit task and Verbal Parity task. These have successfully shown how visual and verbal information could be used during a visual task and have support the research from Logie (2011). However, it is still unclear as to how a Central Executive component could contribute to the working memory architecture during a visual change detection task. As the current study was intending to use the same interference tasks that were used during the quantitative task, again, future research could be suggested to use a more executive interference task to see whether a Central Executive component is being used. If a task such as random tapping (Brown & Wesley, 2013) was shown to have interference effects then this could mean that there is a larger component at use than the Episodic Buffer. Logie (2011) suggested that the Episodic Buffer was used to integrate the visual and verbal information; however, it was not stated as to whether the Episodic Buffer then directed this information to the correct component after integration. This is where a more Central Executive component (Baddeley, 2012) could be at use and further dual task investigations with executive interference could give a clearer idea of any contributions of the Central Executive.

A second limitation of the current study is the division of the smaller and larger size changes in the visual arrays. The current task was created without the knowledge of any percentage change analysis, and the numbers of the array with certain percentage changes were added based upon the performance levels of the qualitative pilot study. This meant that the task did not include an equal proportion of small and large changes and participants may have found the task too simplistic with the amount of larger changes that there actually were. Future research could use a 25% divide of smaller (5 and 10%) and larger (15 and 20%) changes to ensure equal numbers of the size changes.

To further investigate the effects of the verbal interference task and lack of effects from the visuospatial interference task, ERP investigations could be used. This will be carried out in the next stage of the current doctoral thesis. The ERP component named the N400 can be used to look at verbal representations within working memory tasks (Riby and Orme, 2013) and the current thesis will aim to again look at any differences between the large and small change stimuli. The N200, on the other hand, can be used as an indicator of early visual processing (Luck, 2005). In the next study of the current doctoral thesis, electrophysiological data could be collected in an attempt to understand why the visual interference task did not interfere with the qualitative shape change detection task. If the N200 is activated and also the N400 is activated, then the primary task may be seen to use early visual processing and verbal processing, and this task may be seen as multicomponent (Logie, 2011). However, if no N200 is activated then this could indicate a lack of visual representation use in the qualitative change detection task and any lack of 'visual interference effects' could be due to the primary task not being a visual task itself.

6.11 Mu Comparison of Study 3 and 4

To directly compare the Mu scores from the Quantitative (Study 3) and Qualitative (Study 4) experiments, a 2(array size) x 2(interference type) x 2(study type) mixed ANOVA was conducted on the data, using the array size and interference types as within-groups factor and study type as the between-groups factor.

Table 6.5. Means and standard deviations of the error rates of each interference condition.

	Quantitative		Qualitative	
	Array 4	Array 6	Array 1	Array 2
Visuospatial	91.88(9.72)	98.86(7.71)	105.80(19.84)	101.90(8.56)
Verbal	87.29(7.06)	86.86(5.38)	88.70(12.41)	92.10(13.77)

Table Notes:

Main Effects

The 2 x 2 x 2 mixed ANOVA demonstrated that there were no main effects of array size found, *$F(1,19)= .411$, $p=.529$, partial $\eta^2 = .021$, Wilks Lambda = .979.* There was, however, a significant main effect of interference type*, $F(1,19)= 14.354$, $p=.001$, partial $\eta^2 = .430$, Wilks Lambda = .570.* The visuospatial interference has a larger Mu score of 99.61 (SD = 11.20) compared to the verbal interference with a mean of 88.73 (SD = 9.65), indicating a larger interference effect with verbal interference.

There was a significant main effect of study type, *$F(1,19)= 5.029$, $p=.037$, partial $\eta^2 = .209$.* The quantitative task had a smaller Mu score of 91.22 (SD=7.46) compared to the qualitative task Mu score of 97.12 (SD=13.40) indicating that overall, interference effects were greater within the quantitative task.

Interactions

The interaction between the array size and study type was found to be not significant *$F(1,19)= .558$, $p=.464$, partial $\eta^2 = .029$, Wilks Lambda = .971.* The interaction between interference e type and study type was found to be not significant, $F(1,19)= .806, p=.381,$ *partial* $\eta^2 = .041$, *Wilks Lambda = .959.* The interaction between array size and interference type was found to be not significant, $F(1,19)<.001, p=.998$, *partial* $\eta^2 <.001$, *Wilks Lambda = 1.00.* The interaction between array size, interference type and study type was also found to be not significant, $F(1,19)= 3.898, p=.063$, *partial* $\eta^2 = .170$, *Wilks Lambda = .830.*

6.12 Mu Comparison Discussion

The aim of the current analysis section was to directly compare the Mu scores for the quantitative (Study 3) and qualitative (Study 4) change detection protocols. Analyses revealed no effects of array size, indicating that interference effects did not differ in any form when array size increased. Overall, greater verbal interference effects were found in both the quantitative and qualitative protocols and this was demonstrated by the smaller Mu scores for the verbal interference conditions. Finally, an effect of study type was present, suggesting that the quantitative task may have been more susceptible to interference effects. This was demonstrated for the smaller Mu score from the quantitative change detection protocols.

The smaller Mu scores with regards to the quantitative change detection protocols could suggest to current researchers that this task has a greater ability to recruit both visual and verbal attentional resources, indicating a more multicomponent approach to this type of change detection task in particular and supporting suggestions made from the domain general literature (Brown & Wesley, 2013; Hamilton et al., 2003; Shipstead & Yonehiro, 2016). The qualitative task, however, may not initially be seen as a domain general task due to the presence of verbal interference effects only from the initial Mu analysis. As the visuospatial interference was shown to have no effect, suggestions could be made to indicate that this task may recruit any type of resource available. The use of colours within the quantitative change detection protocol may prompt participants to use both visual and verbal information if the colours of the squares can be grouped into meaningful displays (e.g. colours of a country flag). Strategies of this nature would require the recruitment of visual resources when the colours of the squares are being processed, but also verbal resources and Long Term Memory use when verbal labels may be attached to the encoding array. In contrast to this, the qualitative task does not allow participants to use such visual and verbal strategies due to the use of only three colours and different size shapes within the arrays. Applying a verbal label may be difficult when encoding different percentage changes as potentially the quantitative labels of 'bigger' and 'smaller' may not be enough to distinguish the exact size change presented.

To further investigate the use of both visual and verbal attentional resources in both types of change detection tasks, the tasks will now be used in both an electrophysiological and a developmental context to look closer at the functional working memory architecture of the two tasks.

6.13 Chapter summary

The current chapter used a dual task procedure, similar to that of study 3, and investigated the working memory representations used by the qualitative change detection task. Results demonstrated that verbal interference effects were present; however, it was questioned as to where these effects were occurring. As a result, data was divided into smaller and larger changes, finding that the interference was actually hitting larger changes in visual arrays. This now raises questions to the creation of future qualitative tasks. If qualitative tasks are made of all small changes then this could essentially suggest that the task may not be susceptible to interference.

The next chapter aims to provide further evidence towards whether change detection tasks are multicomponent or domain specific. To do this, electrophysiological data will be collected to look at the brain waves in relation to both the quantitative and qualitative change detection tasks.

CHAPTER 7

ERP Investigation

7.1 Chapter Overview

Chapters 5 and 6 of the current doctoral thesis looked at the potential incorporation of verbal representations in two visual change detection tasks, concluding that visual tasks may make use of verbal representations in memory, with evidence from dual task behavioural data. However, in the qualitative change detection task, with small changes, the secondary task executive resources did not seem to be employed. One way to investigate this further is by looking at the electrophysiological properties of the brain associated with both change detection tasks, in particular, the use of the verbally related N400 component and the visual specific N200 component. It is anticipated that should there be semantic recruitment during the encoding of the visual information then this would be indexed by heightened N400 waveform activity.

7.2 Introduction

Electrophysiological properties of the brain have been studied for many years and can show the brain's electrical activation in relation to real time cognitive processing. Event related potentials can be used to look at how the brain processes information, and can give us information about the potential memory systems which are used (Luck, 2005). The use of the semantically related N400 (Riby and Orme, 2013) and the visual specific N200 (Luck, 2005) are two developing ERP components which may be of use during the investigation of the current change detection tasks. Below, these components are discussed in relation to how they may be used when investigating the working memory architecture of both tasks.

The N400 ERP component is one which is linked to the use of semantics and language processing abilities (Chwilla, Brown and Hagoort, 1995). However, more recent work has focussed on how the component can be linked to visual working memory paradigms and not just verbal ones (Kutas and Federmeier, 2011). This negative waveform presents itself at approximately 400 milliseconds of time, whether this is the first 400 milliseconds of encoding, or the first 400 milliseconds of retrieval (Luck, 2005).

More recent work has focussed upon the semantic contributions to visual working memory architecture (Riby and Orme, 2013) instead of the more purely phonological view of the N400 as suggested by Kutas (1993). Kutas and Federmeier (2011) suggested that research emphasis has slowly become more visual stimuli oriented, ranging from asking participants to view lists of words to nowadays asking participants to view images, and use visual working memory instead (Smith and Guster, 1993).

Earlier work, such as that of Brown and Hagoort (1993) focussed upon the N400 within a semantic priming context. It was suggested that semantic priming could elicit a larger N400 over the midline electrodes, suggesting that this component may be related to long term memory storage and semantic memory. Similar findings from Kiefer (2002) suggested the presence of heightened activation of the N400 within a semantic context, in particular over the parietal occipital regions. Kiefer (2002) also suggested that the N400 is not as area specific as first thought with the use of a letter array memory task. The parietal occipital regions were activated in their research whereas previous literature suggested the midline areas to be with the highest activation.

Kellenbach, Wijers and Mulder (2000) on the other hand, demonstrated that verbal priming may not be the only type of priming to elict a negative N400 wave. Visual-perceptual priming can also do this, specifically over the central parietal areas of the brain. Visual-perceptual priming is an example of priming that refers to visually related aspects of two words, for example if two words could be used in the context.

Eimer (2000) also used the N400 in a visual context by looking at the encoding and recognition of faces. This investigation suggested a larger N400 amplitude, over the central electrodes, when familiar faces were presented, indicating the use of long term memory and semantic involvement. In later work, Neumann and Schweinberger (2008) used the N400 as evidence of semantic processing of faces, again suggesting both central and parietal areas to be the most important brain regions when participants were asked to ignore irrelevant faces. The activation pattern of the N400 demonstrated that ignoring the faces had no effect of the N400 and results showed semantic processing of material even when being asked to ignore it.

Semantic representation use is not solely limited to verbal material (Nittono, Suehiro and Hori, 2002). Nittono et al. (2002) used high and low imaginable words to show an N400 waveform during trials which included both high and low imaginable words. Researchers, here, suggested that even when a small amount of imagery is possible (in low imagery words such as Chinese characters), the activation of the semantic networks within the brain are present. Thus, the N400 component has been viewed as a very good measure of semantic involvement and was demonstrated in both the left and right hemispheres when semantic processing was potentially being used.

Riby and Orme (2013) is one of the most recent pieces of research to investigate the semantic contributions to a visual task such as the Visual Patterns Test. Within this research, the N400 was shown to be activated during the encoding of visual patterns. Riby and Orme (2013) manipulated versions of the visual patterns test to include a high and low semantic condition (Orme, 2009). The high semantic patterns were patterns that could be easily given a meaning to and that could potentially be displayed as other object, for example letters or objects. One example was having an ‘L’ shape using three matrix squares. The low semantic patterns were patterns which could not be so readily organised, by Long Term Memory, into recognisable shapes. Riby and Orme (2013) found that the N400 had a larger N400 amplitude specifically within the high semantic patterns condition, indicating that a visual task may use verbal information as previously suggested in the behavioural research (Brown & Wesley, 2013; Hamilton et al., 2003; Rudkin et al., 2007).

At present, Riby and Orme (2013) is one of the most recent research studies which has focussed solely upon visual working memory tasks. For the current ERP investigation, another type of visual working memory task format will be used - the change detection paradigm of Luck and Vogel (1997) to discover if this type of visual working memory task could also indicate the presence of semantic involvement and verbal information use.

To contrast the N400, researchers will also be using a visual representation marker known as the N200 ERP component. Allison, McCarthy, Nobre, Puce and Belger (1994) looked at the N200 component, indicating activation for many types of visual stimuli including faces, words, numbers and colours. As colours were shown to cause early activation indicting early visual processing, this component may be appropriate to use in the current investigation as the first task is a colour based change detection task. Allison et al. (1994) demonstrated that the N200 may be colour specific and was activated in the left hemisphere.

Berti, Geissler, Lachmann and Mecklinger (2000) demonstrated that the N200 is activated at more frontal electrode sites during the encoding of more complex visual stimuli. By using a visuospatial memory task, consisting of a dot pattern, it was shown that the more complex stimuli of eight symmetrical dot patterns had a heightened N200 component. Contrasting research from Nobre, Allision and McCarthy (1998) suggested that the N200 was associated with selective attention and attentional control and not simply array complexity. The N200 can therefore putatively be used both as a marker of complexity and attentional control within the current investigation. Support for the N200 being a marker of greater attentional control was also suggested by Morgan, Jackson, Klein, Mohr, Shapiro and Linden (2010) who used the recognition of both colours and angles in their study. By using a dual task context of remembering both colours and angles in one array, it was demonstrated that the dual task required greater attentional control and displayed the larger N200 over parietal occipital regions compared to the single task condition of only having to remember colour.

Task difficulty is another explanation of why the N200 may be greater in some tasks compared to others (Senkowski and Herrmann, 2002). Senkowski and Herrmann (2002) used the N2b component, a sub component of the N200 to look at task difficulty. As the ‘difficult’ visual discrimination task was more visually demanding where participants had to discriminate between to different versions of one colour, the N2b component was activated, indicating increased attentional control with the more difficult task. This is in line with the suggestions made form Nobre et al. (1998) who had indicated that attentional control was an important characteristic of the N200 components.

Du, Zhang and Zhang (2014) proposed that the N200 is a purely visual component with no influence of verbal semantics during the processing of visual arrays. By looking at the semantic processing of Chinese visual words (word recognition), it was discovered that the N200 was not activated by the words which involve semantic priming. This contemporary investigation is very useful for the current doctoral study as it gives a basis of why the N200 will be used. As Luck (2005) had previously proposed this component to be a visual specific one, the research from Du et al. (2014) has shown support for this and has given indications that more recent research is still developing similar findings. It is hoped that the current doctoral study will also use the N200 as more of a marker of visual processing and visual representation use.

The final component of interest to the current doctoral investigation is the positive component known as the P300. Riby and Orme (2013) suggested that this component was related to processes within encoding and suggested that an increase in amplitude would indicate deeper encoding of information. The P300 has been investigated in several contexts using both visual (Koivisto & Revonsuo, 2003) and verbal (Dunn, Dunn, Languis & Andrews, 1998) stimuli as well as being used in a handedness context (Polich & Hoffman, 1998) to see if there are any differences between left and right handed individuals. Clinical contexts, such as in patients with mild cognitive impairment have also been used (Gozke, Tomrukcu & Erdal, 2013) to see which areas of the brain are most related to the P300 component.

Lavric, Forstmeier and Rippon (2000) suggested that the P300 component, which is also known as P3, can be related to encoding mechanisms in the working memory architecture. In their research, an Analytical Task (a task that only has one solution) and a Primary Task (a task where there could be several solutions) were used. It was found that the P300 was more pronounced in the frontal regions of the brain with regards to the Analytical Task, suggesting the link between the P300 and the use of several cognitive functions within a task. The potential use of several cognitive functions would mean that the task would require greater attentional control, however, unlike the N200, the P300 is less visual specific, and heightened amplitude can be associated with greater attentional control of any type of task.

Two similar pieces of research have looked at the differences in ERP components when both change detection and change blindness is detected. Koivisto and Revonsuo (2003) and also Turatto, Angrilli, Mazza, Umilà and Driver (2002) looked at the differences of the P300 between these two groups. Koivisto and Revonsuo (2003) used a simple change detection procedure with size 1 and 8 arrays to look at conditions with changes, no- changes and undetected changes. It was found that the P300 component elicited larger waves when changes had been detected compared to when participants failed to detect the changes.

Turatto et al. (2002) used a slightly different change detection paradigm, however found similar to results with regards to the P300. In their research, both foreground and background changes were present and conditions were set as to whether participants could detect background and foreground changes when being cued. The larger P300 amplitudes were again present for those who successfully detected changes, in particular in the conditions where participants had been cued. The P300 was suggested to be present in the frontal regions and parietal regions of the brain, which again are highly associated with cognitive functions such as encoding mechanisms and greater attentional control.

Although the current investigation will not be looking at the differences between changes versus no-changes, Koivisto and Revonsuo (2003) and Turatto et al. (2002) are useful pieces of research to understand as it gives the current investigation a reasons to use the P300 component. As this component has been highlighted to be an important one within a working memory change detection paradigm, this will be useful to current researchers as attentional differences between quantitative and qualitative change detection P300s can be determined which can add to this increasing area of investigation.

Similarly, Potts (2004) defined the P300 as a marker for controlled attention. In an investigation using undergraduate students and a visual target detection paradigm with three conditions (pressing a key when a rare target appeared, looking at the stimuli, or silently count the number of rare targets), it was demonstrated that the P300 was activated during the active testing blocks. For example, larger activations were apparent when participants had to press a key or count the amount of rare targets instead of simply looking at the stimuli. A larger P300 during the active tasks could suggest that the P300 is be related to encoding processes such as control of attention (to a target) as a target presence effect was also present relating to the P300.

In line with Potts (2004), a review from Polich (2007) proposed similar used of the P300. The P300 was discussed in detail within this review and it was suggested that a larger P300 waveform could mean a greater focus of attention. Polich (2007) suggested that when more attentional resources are being used during a task then this could create smaller P300 amplitude as attentional control can be reduced with the increase of tasks to be completed. Discussion of research form Curran and Cleary (2003) Curran (2004) used images and Snodgrass drawings to support the suggestion of the links between the P300 and the greater use of attentional control.

Morgan, Klein, Boehm, Shapiro and Linden (2008) however looked at the P300 (known as the P3b here) in relation to memory load and not attentional control, using a face stimuli change detection paradigm. In more difficult conditions, faces were presented as scrambled objects meaning a larger memory load was needed to encode these items. It was demonstrated that the late P3b decreased with increasing work load at encoding and retrieval, indicating that as the memory load increased, the attentional control decreased causing a decrease in the P3b. As with the research from Polich (2007), Morgan et al. (2008) suggested that there is a decrease in amplitude of the P300 due to the fact that there are fewer resources in memory to assist with the increasing cognitive demands of the task. The fewer resources are due to the increasing work load as each extra ‘face’ in memory would have been allocated more resource space.

Pinal, Zurrón and Diaz (2015) used the P300 in an ageing context to show that this component is highly related to encoding processes within memory. In this investigation, young participants (mean age of 23.85) and older participants (mean age of 67.80) were compared when completing a delayed match sample (DMS) task. A DMS task requires the participant to store an image in memory and then at retrieval, the participant has to identify which one (of three) is the same as in the encoding image. It was found that the P300 amplitude decreased with age, as working memory processes and encoding strategies decline with age. This investigation is one of importance for the current doctoral investigation as it gives a more contemporary view of the P300. Still, in 2015, the P300 can be seen as an attention allocation component and also a component that is related to working memory functions. Despite the current doctoral investigation only using a younger sample, the research from Pinal et al. (2015) has shown that this area of research is still ongoing and therefore gives current researchers a good reason for continuing with the investigations of the P300 and using this as a marker attentional control and increased encoding.

7.3 Rationale for study 5

Riby and Orme (2013) supported theoretical perspectives from Logie (2011) and also Brown and Wesley (2013) who demonstrated that visual tasks may use verbal representations. By using the N400 as a verbal semantic indication, researchers found heightened activation during a visual matrix task. The aim of the current study is to use a similar ERP methodology to Riby and Orme (2013) to investigate the electrophysiological properties of the previously contructed quantitative and qualitative change detection tasks. The N400 will be used as an indication for semantic representations use and the N200 will be used as a marker for visual (attention) specific information use. The P300 component will also be used as this component was suggested to be an important aspect of encoding and a marker of attentional control by researchers such as Riby and Orme (2013) and Pinal et al. (2015). The comparison of the N200 and N400 components, and the addition of the P300 component, will hopefully provide support for the behavioural data of the previous interference paradigms in experiments 3 and 4 of the current thesis. These two experiments indicated the use of both visual and verbal information during both change detection tasks (large qualitative changes only) and the current electrophysiological experiment aims to try and provide further evidence of this.

7.4 Predictions

1) When comparing the quantitative 4 and quantitative 6 tasks, the quantitative 6 task will be shown to use more semantics, indicating an array size effect of the N400 and N200 within this task. This is due to the fact that an array size of 6 is over the capacity limit and will need to recruit verbal resources (semantics) once the visual resources have been used.
2) When comparing the qualitative 1 and qualitative 2 tasks, there will be no difference in peak latency or mean amplitude of these tasks. In the previous study of the current doctoral thesis (study 4), similar performance levels were found with array sizes 1 and 2, suggesting that there will be no difference in the recruitment of resources here.
3) When overall comparing the quantitative and qualitative tasks, there will be a larger N200 and N400 for the quantitative task. Study 2 of the current doctoral programme suggested that both visual and verbal resources were being used during this task; therefore, the two ERP components will be greatest during this task. The qualitative

tasks, in particular the smaller changes, will recruit fewer verbal resources therefore the N400 will have a less negative deflection.

7.5 Method

7.5.1 Design

A 2 x 2 x 2 x 4 repeated measures design was used. Factor 1 was the task type, consisting of 2 levels - quantitative or qualitative task type. Factor 2 was the array size consisting of 2 levels – small (1 and 4) and large (2 and 6). Factor 3 was the hemisphere with 2 levels – left and right. Factor 4 was the brain region consisting of 4 levels - frontal, frontal-central, central-parietal, parietal-occipital. This design was used for the N400, P300 and N200 ERP components separately for each statistic of mean amplitude and peak latency.

7.5.2 Participants

21 participants, 5 males and 16 females, with a mean age of 21.80 (standard deviation of 3.99) took part in the investigation. All participants were from the area of Newcastle-upon-Tyne, had no condition of colour blindness and were all right handed to reduce any effects of left-right hemisphere interactions. Participants also had no condition such as an anxiety related disorder.

7.5.3 Materials

7.5.3.1 Memory Tasks

The baseline primary tasks from study 3 and 4 were used for the current investigation. Please see chapters 5 and 6 for details of these two primary tasks. In the quantitative tasks of array sizes 4 and 6, participants had to decide if probe square stimulus presented was the same or different colour than any in the previous encodied memory array. In the qualitative size change detection tasks consisting of array sizes 1 and 2, participants had to decide if a probe shape was bigger or smaller than the corresponding one presented in the memory array.

Each of the four change detection tasks consisted of a total of 60 trials. In both quantitative colour change detection tasks, 30 trials used the ‘same’ colour in the retrieval array and 30 trials used a ‘different’ colour in the retrieval array. In both qualitative size change detection tasks, 30 trials were used to show smaller changes in shape sizes which consisted of either 5% or 10% changes in shape area. The final 30 trials consisted of larger changes which were either 15% or 20% changes in area.

Each experimental trial consisted of a 500 millisecond encoding image before a 900 millisecond maintenance interval. A 3000 millisecond probe image was presented and this was the time where participants’ behavioural responses were recorded. Please see Chapter 5 (Figure 5.1.) and Chapter 6 (Figure 6.1.) for visual examples of these trials.

At the beginning of each task, participants had to press the space bar to start, and then had to respond with the appropriate ‘z’ and ‘m’ keys. The z key was pressed when the square was a different colour (quantitative) or a larger size (qualitative. The m key was pressed when the square was the same colour (quantitative) or a smaller size (qualitative). These tasks took approximately 5 minutes each and participants were given a short break between tasks if needed.

7.5.3.2 EEG Equipment

EEG recordings were taken using a 32 channel electrode cap (Bio-semi). Electrode sites included FZ, CZ, PZ, OZ, FP1, AF3, F7, FP2, AF4, F8, F3, FC1, FC5, F4, FC2, FC6, C3, CP1, CP5, C4, CP2, CP6, P7, P3, PO3, P8, P4, PO4, T7, T8, O1, O2, CMS and DRL.

The groupings of electrodes included four midline sites (FZ, CZ, PZ, and OZ) and also included were both right and left hemisphere distinctive regions. These regions were: Left-Frontal (FP1, AF3, F7), Right-Frontal (FP2, AF4, F8), Left-Frontal-Central (F3, FC1, FC5), Right-Frontal-Central (F4, FC2, FC6), Left-Central-Parietal (C3, CP1, CP5), Right-Central-Parietal (C4, CP2, CP6), Left-Parietal-Occipital (P7, P3, PO3), and Right-Parietal-Occipital (P8, P4, PO4). These groupings were taken from Riby and Orme (2013) as this was the main key study regarding the methodology of this investigation.

To indicate eye blink movements, electrodes were placed above and below the left eye so that these movements could be eliminated during analysis. These eye electrodes were not used during the analysis procedure

Analyses were conducted using NeuroScan Edit 4.3/4.5 which included ERP averaging, filtering (bandpass high at .001, low pass at 30), smoothing (21 points), baseline correction and artefact rejection (rejection criteria of -100M to +100 MV). Comparisons were made between the ERP data of the quantitative and qualitative tasks and grand averages were taken across all of the data sets. Data was extracted for the mean amplitudes and peak latencies of each ERP component (N200, N400, P300). As only encoding ERP recordings were being analysed, there was no need to separate the data into ‘same/different’ trials or ‘big/small’ trials.

7.5.3.3 Components

Visual inspection of the EEG grand average data allowed the latencies of the N200, N400 and P300 to be identified. These were defined as 135ms-260ms for the N200 component, 250ms-470ms for the N400 component and 260ms-450ms for the P300 component. To define the latencies of the N200 and P300, electrode site PO3 was used as these components were more clearly visible at PO3. To define the N400 component, electrode F8 was used.

7.5.4 Procedure

The current investigation was ethically approved by the the University Health and Life Sciences Ethics Committee. Participants were recruited through a poster advertisement or through a study recruitment system at Northumbria University.

Before the experiment took place, participants were given an information sheet and were asked to sign a consent form to give their consent to take part. The participant was reminded of his/her right to withdraw at any time during the investigation.

During the preparation before experimental procedure, participants were asked to brush their hair before the researcher placed a fabric cap on their heads. The researcher then measured the head of the participant (from the forehead to the back of the skull, naison to the inion) so that a central point could be noted and the EEG cap could be adjusted if necessary.

The researcher used a non-alcoholic face wipe to ensure that the participant's skin was clean around the eyes so that the eye electrodes could be attached above and below the eye. At this point, the researcher began to attach the electrodes to the participants' skin (under and above the left eye so that eye blinks could be identified in the data) using electrode stickers. Electrodes were then attached to the EEG cap using saline gel which was injected into each electrode compartment. The researcher had to match each electrode number with the corresponding compartment in the EEG cap.

At this point, the EEG electrodes were attached to the computer equipment so that the recording of the EEG waves could be started.

Participants were asked to remain calm and sit still for approximately two minutes so that researchers could see that the electrophysiological data was recording appropriately. Testing began when the equipment had been checked and when EEG waves appeared to be recording appropriately.

The experimental change detection tasks were explained to the participant using the perceptual information sheets. Please see Appendices A and B for these information sheets.

The experimental testing phase then began. Participants had to complete all four visual memory tasks, which had been randomly ordered.

At the end of the testing phase, participants thanked for their time and were fully debriefed with the aims of the study and contact details of the researcher.

The EEG equipment was removed from the participant and was cleaned before being stored away in the appropriate way.

7.6 Results

Only 16 participants' data sets were used during the analysis phase due to EEG recording issues. 4 participants demonstrated a high amount of noise interference with several electrodes; therefore, this data was not used. 1 participant did not complete the testing phases therefore this data set was not used.

7.6.1 Behavioural Results

Array size scores were averaged so that the analysis included only one quantitative (array sizes 4 and 6) and one qualitative (arrays sizes 1 and 2) measure. Two one-way repeated measures ANOVAs were conducted to look at any differences in the memory scores and reaction times of each task type. Table 7.1. presents the means and standard deviations of the scores and reaction times for each task type.

Table 7.1. Means (and SDs) of both the score and reaction time of the quantitative and qualitative change detection tasks

	Mean Score (out of 60)	Mean Reaction Time (ms)
Quantitative Task	45.84(4.43)	715.38(117.73)
Qualitative Task	48.31(7.96)	756.90(171.72)

Table Notes:

There were no significant differences associated with the memory scores on each task *$F(1,15)=1.234$, $p=.284$, partial $\eta^2=.076$*.

There were also no significant differences associated with the reaction times of each task type, *$F(1,15)=2.203$, $p=.158$, partial $\eta^2=.128$*. Please see Table 7.1. for the mean scores and reaction times of the tasks.

7.6.2 Electrophysiological Data Analysis

For each component (N200, P300 and N400), the mean amplitude and peak latency statistical measurements were taken. The midline electrode sites (FZ, PZ, OZ and CZ) were not included in the analysis. Electrode sites T7, T8, O1 and O2 were also not included in the analysis as these had been disregarded by Riby and Orme (2013).

For each statistic of mean amplitude and peak latency, a 2 (Task: Quantitative, Qualitative) x 2 (Array size: 4 and 6 for quantitative and 1 and 2 for qualitative) x 4 (Region: Frontal, Frontal-Central, Central-Parietal, Parietal-Occipital) x 2 (Hemisphere: Left, Right) repeated measures ANOVA was conducted on each ERP component.

Correlations were also produced between the reaction times of the correct trials, the score on each task and the region of each component that was of highest activation.

Post Hoc Analyses

Where post hoc analyses were needed for a main effect given from an ANOVA, the Bonferonni function within the ANOVA SPSS analysis was used which automatically adjusts the alpha level accordingly. When following up an interaction effect, this Bonferroni function was not used and instead, paired smaples t-tests were conducted with the appropriately adjusted p values for each correction (for example, alpha/number of hypotheses tested).

Mean Amplitude

Table 7.2. Means and standard deviations (in MV) of the Mean Amplitudes of the N200, N400 and P300 for the Quantitative change detection tasks within each brain region.

	Frontal	Frontal Central	Central Parietal	Parietal Occipital
N400	-1.18(1.76)	-.64(1.48)	1.22(.85)	1.43(2.08)
N200	1.52(1.56)	1.80(1.12)	.49(.55)	-2.44(1.82)
P300	-1.29(1.80)	-.75(1.49)	1.25(.88)	1.60(2.14)

Table Notes:

Table 7.3. Means and standard deviations (MV) of the Mean Amplitudes of the N200, N400 and P300 for the Qualitative change detection tasks within each brain region.

	Frontal	Frontal Central	Central Parietal	Parietal Occipital
N400	-2.05(1.37)	-.86(1.32)	1.28(.84)	1.71(1.56)
N200	-.17(1.24)	.49(.78)	.43(.45)	-.53(1.44)
P300	-2.13(1.39)	-.89(1.36)	1.31(.84)	1.78(1.63)

Table Notes:

<u>N200 Mean Amplitude</u>

For the N200 ERP component, a significant main effect of brain region was found, $F(3,9)=12.874$, $p=.001$, *partial* $\eta^2=.811$. Bonferroni post hoc analyses demonstrated that the parietal occipital region (MV = -1.273, SD=1.77) showed a larger negative deflection of mean amplitude compared to the frontal region (MV=.525, SD = 1.52, p=.048), frontal central region (MV=1.295, SD=1.25, p=.005) and central parietal region (MV=.472, SD=.66, p=.001).

A significant main effect of task was also found, $F(1,11)=22.223$, $p=.001$, partial $\eta^2=.669$, with the quantitative task having a less negative deflection (MV= .417, SD=1.26) compared to the qualitative tasks (MV= .093, SD=97). Please see Tables 7.2. and 7.3. for the means and standard deviations of the N200 mean amplitudes.

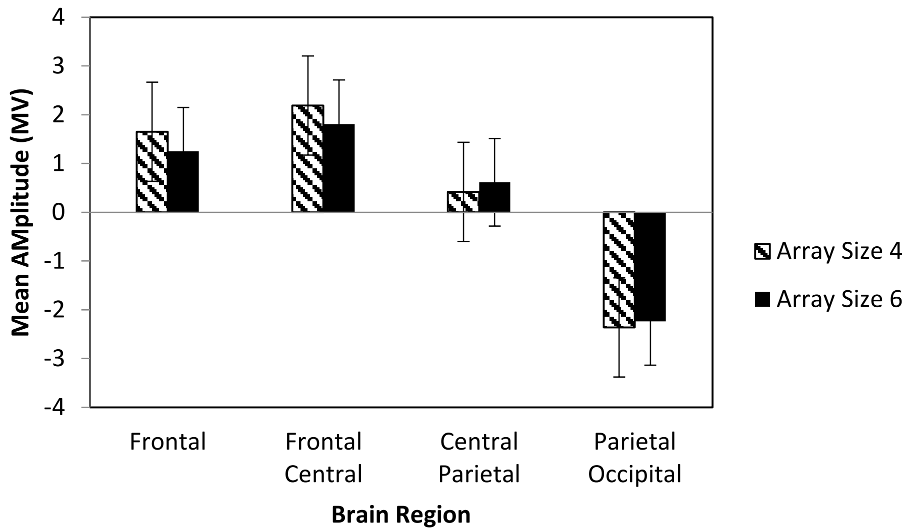

Figure 7.1. The interaction between region and array size for the mean amplitude of the N200 during the quantitative change detection task.

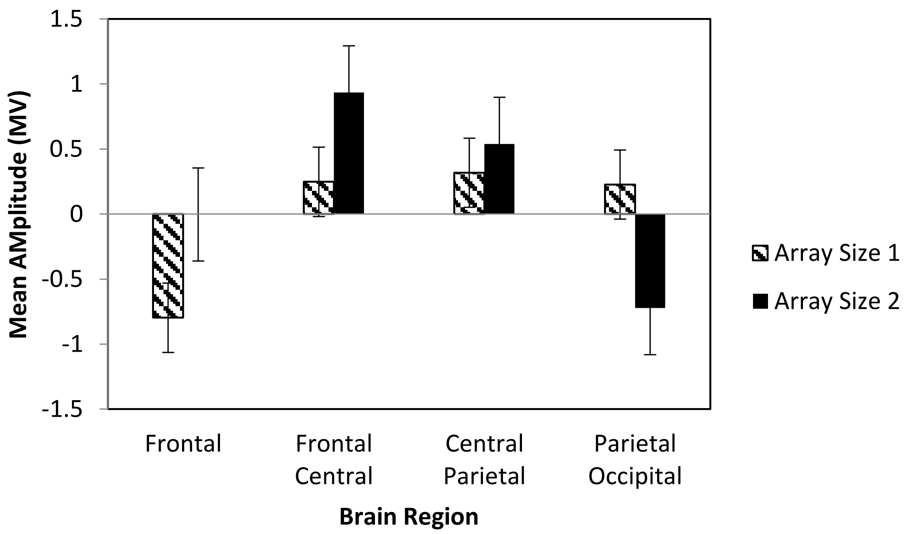

Figure 7.2. The interaction between region and array size for the mean amplitude of the N200 during the qualitative change detection task.

A task x array x region interaction effect was also present, *F(3,9)=4.402, p=.045, partial* η^2*=.595*. Figures 7.1. and 7.2., illustrate this interaction effect. Paired samples t-tests (one-tailed tests) were conducted on the data to follow up this interaction.

It was found that for the quantitative change detection task, there were no significant array size differences in contrast to the qualitative change detection task, suggesting a more uniformed data pattern for the quantitative task. For the qualitative change detection task, there were differences between array sizes 1 and 2 for the frontal region (mean difference = -.547MV, p = .39), frontal central region (mean difference = -.589MV, p = .033), central parietal region (mean difference = -.208MV, p = .043), and the parietal occipital region (mean difference = .772MV, p = .010). The difference in consistency of array sizes between the quantitative and qualitative change detection tasks give the suggestions of this interaction. The quantitative change detection task demonstrated a more uniform pattern of results (with no array size differences) compared to the qualitative change detection task.

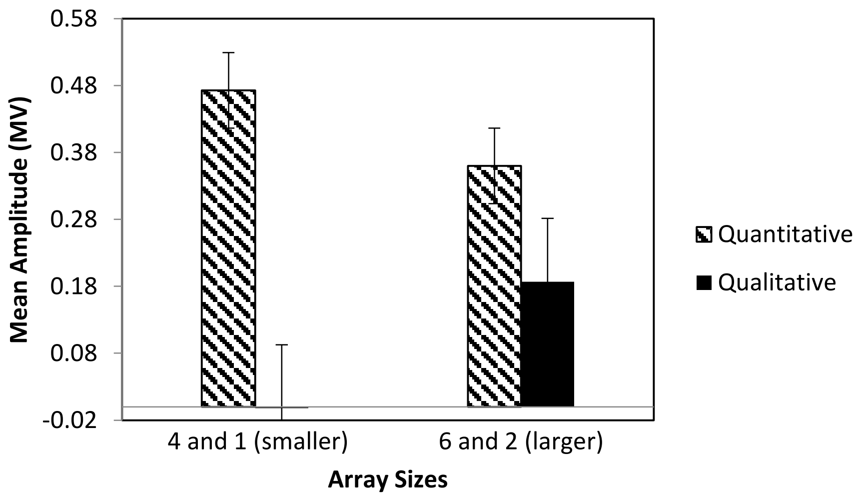

Figure 7.3. The interaction between task and array size for the mean amplitude of the N200.

A task x array interaction effect was also present, *$F(1,11)=6.123$, $p=.031$, partial $\eta^2=.358$*. Please see figure 7.3. for graphical representation.

Paired samples t-tests (one-tailed tests) were conducted to follow up on this interaction. These t-tests demonstrated that the difference between each change detection task was larger for the smaller array sizes of 4/1 (mean difference = 0.4748 MV, p =.001) compared to the differences of the larger array sizes of 6/2 (mean difference = 0.173MV , p= .0025). The smaller array sizes demonstrated the larger difference in mean amplitude.

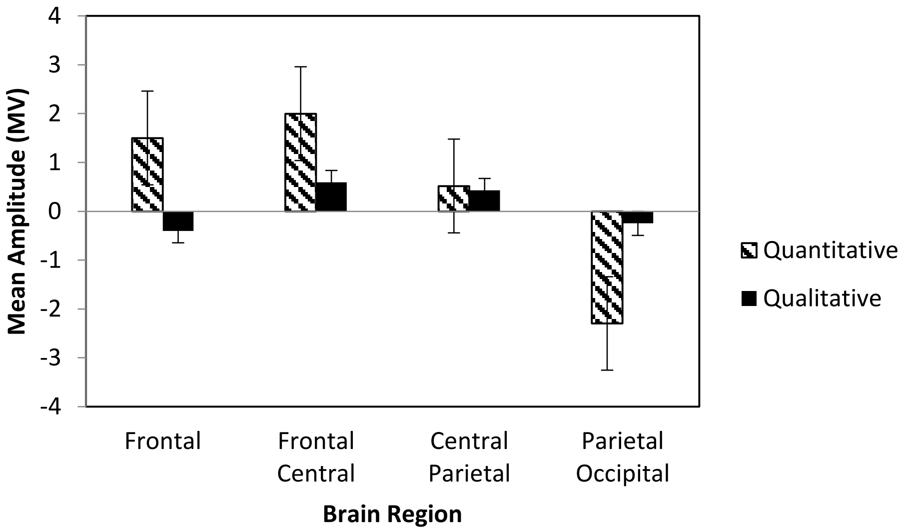

Figure 7.4. The interaction between task and region for the mean amplitude of the N200.

A task x region interaction effect was also present, *$F(3,9)=12.957$, $p=.001$, partial $\eta^2=.812$*. Please see Figure 7.4. for graphical representation.

Paired samples t-tests (one-tailed tests) were conducted to follow up on this interaction. The interactions, appear to be coming from the differences in task type mean amplitude for the frontal region (mean difference = 1.704 MV, p <.001) frontal central region (mean difference = 1.308 MV, p<.001) and the parietal occipital region (mean difference = -1.91 MV, p <.001).

P300 Mean Amplitude

For the P300 ERP component, a significant main effect of brain region was found, *$F(3,9)=8.955$, $p=.005$, partial $\eta^2=.749$*. Bonferroni post hoc analyses demonstrated that the frontal region (MV =-1.550) showed the least positivity in mean amplitude compared to the frontal central region (MV = -.568, p=.012), central parietal region (MV =1.385, p=.001) and also the parietal occipital region (MV =1.526, p=.010).

A significant main effect of task was also found, *$F(1,11)=5.750$, $p=.035$, partial $\eta^2=.343$*, with the quantitative task having a larger positive deflection (MV = .301) compared to the qualitative tasks (MV = .096, p=.007). Please see Tables 7.2. and 7.3. for the means and standard deviations of the P300 mean amplitudes.

N400 Mean Amplitude

For the N400 ERP component, a significant main effect of brain region was found, *$F(3,9)=8.829$, $p=.005$, partial $\eta^2=.746$*. Bonferroni post hoc analyses demonstrated that the frontal region (MV =-1.458, SD=1.56) showed a larger negative waveform of mean amplitude compared to the central parietal region (MV =1.356, SD=.84 p=.001).

A significant main effect of task was also found, *$F(1,11)=5.535$, $p=.038$, partial $\eta^2=.335$*, with the quantitative task having a less negative deflection (MV = .309, SD=1.54) compared to the qualitative tasks (MV =.102, SD = 1.27, p=.038). Please see Tables 7.2. and 7.3. for the means and standard deviations of the N400 mean amplitudes.

Peak Latency

Table 7.4. Means and standard deviations (in milliseconds) of the Peak Latencies of the N200, N400 and P300 for the Quantitative change detection tasks within each brain region.

	Frontal	Frontal Central	Central Parietal	Parietal Occipital
N400	358.73(34.44)	358.95(31.28)	339.87(35.68)	329.04(64.14)
N200	185.83(35.11)	172.83(27.44)	185.47(14.12)	201.01(13.08)
P300	328.53(40.52)	325.86(33.19)	353.49(25.69)	349.50(26.8)

Table Notes:

Table 7.5. Means and standard deviations (in milliseconds) of the Peak Latencies of the N200, N400 and P300 for the Qualitative change detection tasks within each brain region.

	Frontal	Frontal Central	Central Parietal	Parietal Occipital
N400	337.35(68.54)	352.02(74.03)	339.56(78.46)	293.54(74.39)
N200	201.77(27.63)	181.43(14.75)	184.10(15.75)	210.86(14.25)
P300	318.03(58.11)	315.91(53.96)	340.23(45.51)	342.04(56.82)

Table Notes:

N200 Peak Latency

For the N200 ERP component, a significant main effect of brain region was found, *F(3,9)=21.597, p<.001, partial* η^2*=.878*. Bonferroni post hoc analyses demonstrated that the frontal region (M = 193.447. SD=31.37) showed a significantly larger peak latency compared to the frontal central region (M = 173.561 SD=21.09, p=.019). The parietal occipital region (M = 207.255, SD=17.29) was shown to have a significantly larger peak latency compared to the frontal central region (M= 173.561, SD=21.09, p=.005) and also the central parietal region (M = 181.525, SD=14.93, p=.001).

A significant main effect of task was also found, *F(1,11)=5.110, p=.045, partial* η^2*=.317*, with the quantitative task having a smaller latency (M = 184.248) compared to the qualitative tasks (M = 193.646, p=.045).

A significant main effect of hemisphere was also found, *F(1,11)=8.954, p=.012, partial* η^2*=.449*, with the left hemisphere having a smaller peak latency (M = 182.161) compared to the right hemisphere (M = 195.733, p=.012). Please see Tables 7.4. and 7.5 for the means and standard deviations of the peak latencies of the N200.

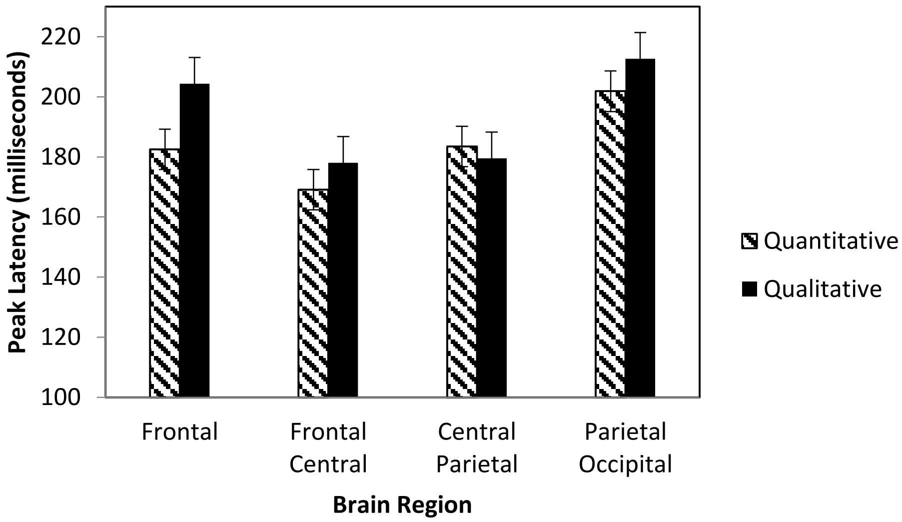

Figure 7.5. The interaction between task and region for the latencies of the N200 ERP component.

A task x region interaction effect was also present, *F(3,9)=7.375, p=.008, partial* η^2*=.711*. Please see Figure 7.5. for graphical representation. Paired samples t-tests (one-tailed tests) were ran to investigate this interaction further. It was discovered that the interaction was found to be coming from the differences in peak latency between the quantitative and

qualitative tasks, for the parietal occipital region (mean difference = -15.93MV, p = .0025) and the frontal regions (mean difference =
-9.849MV, p = .040). No other scores reached significance.

P300 Peak Latency

For this ERP component, there were no significant effects or interactions associated with the peak latency values (all ps >.05).

N400 Peak Latency

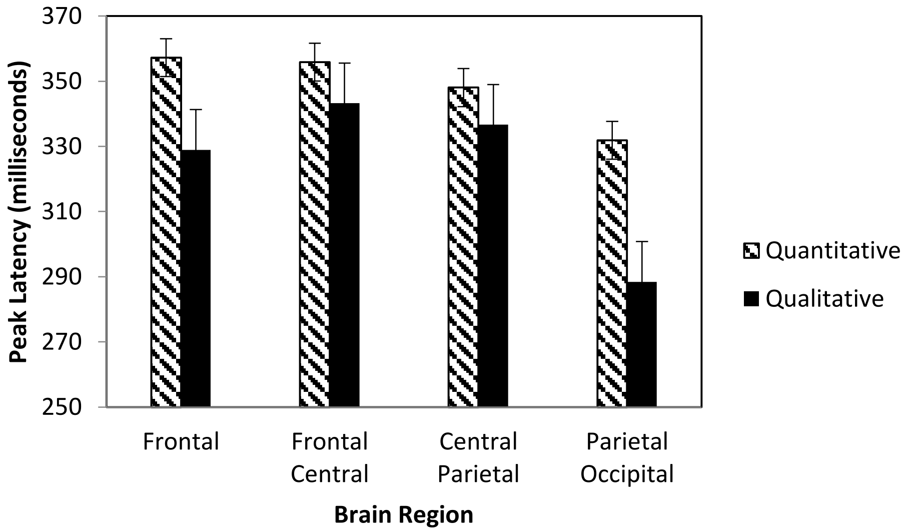

Figure 7.6. The interaction between task and region for the latencies of the N400 ERP component.

For the N400 ERP component, a task x region interaction effect was present, *$F(3,9)=5.520$, $p=.020$, partial $\eta^2=.648$*. Please see Figure 7.6. for graphical representation.

Paired samples t-tests were conducted to investigate this interaction further. It was discovered that the interaction was found to be coming from the differences in peak latency between the quantitative and qualitative tasks, for the parietal occipital region only (mean difference = 35.50ms, p = .049). No other scores reached significance.

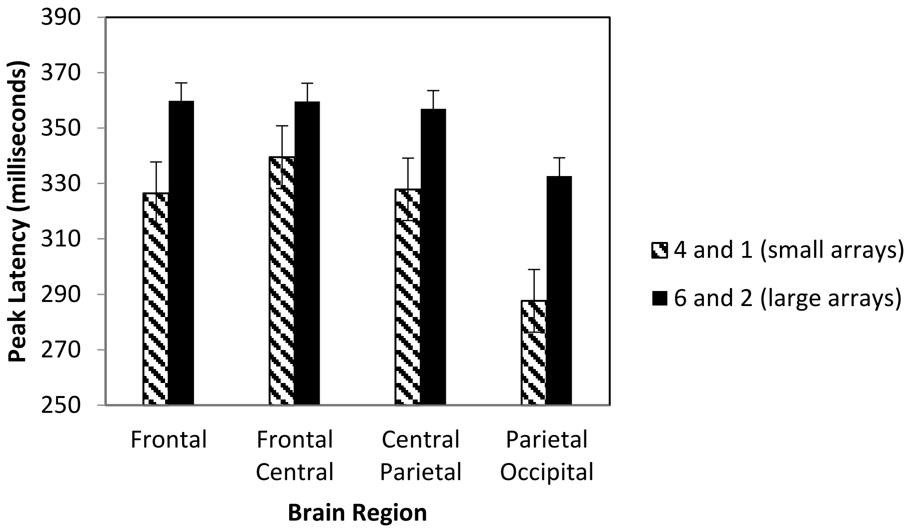

Figure 7.7. The interaction between array size and region for the latencies of the N400 ERP component.

A array x region interaction effect was present, *F(3,9)=6.614, p=.012, partial* η^2*=.688*. Please see Figure 7.7. for graphical representation.

Paired samples t-tests (one-tailed tests) were ran to investigate this interaction further. It was discovered that the interaction was found to be coming from the differences in peak latency between the smaller and larger array sizes, for the parietal occipital region only (mean difference = -36.086ms, p = .041). No other scores reached significance.

7.6.3 Correlations

7.6.3.1 Mean Amplitude

For the mean amplitude, bivariate correlations were carried out between the reaction time, task score and mean amplitude of the region of interest for each ERP component. Correlations were separated into each task type and array size.

N200 (parietal occipital region)

Quantitative Array Size 4

A significant negative correlation was found between the quantitative array size 4 reaction time and the right parietal-occipital region for the N200 (r= -.568, p=.022). No other correlations were significant.

Quantitative Array Size 6

A significant negative correlation was found between the quantitative array size 4 reaction time and the right parietal-occipital region for the N200 (r= -.737, p=.001). No other correlations were significant.

7.6.3.2 Peak Latency

For the peak latency, bivariate correlations were carried out between the reaction time, task score and mean amplitude of the region of interest for each ERP component. Correlations were separated into each task type and array size. No significant correlations were present in the peak latency data for the longest latency.

7.6.3.3 Qualitative Percentage Change Analysis

In line with the percentage change analysis of Chapter 6, the current qualitative data was divided into smaller 5-10% changes and larger 15-20% changes. The previous ERP analysis indicated that for the N200, the parietal-occipital region demonstrated greatest negativity and for the N400 the greatest negativity was presented in the frontal region. As a result of this, the percentage change analysis focuses upon these regions only. Due to the amount of 'correct' responses within the large change condition being 0, one participants' data was not used and only 15 participants' data were used in this section of the analysis.

Table 7.6. Means and standard deviations of the mean amplitudes of the parietal occipital regions associated with the N200.

	Left Hemisphere	Right Hemisphere
Large Changes (15-20%)	-.33(1.12)	-.03(2.10)
Small Changes (5-10%)	-.61(1.49)	.05(1.31)

Table Notes:

Table 7.7. Means and standard deviations of the mean amplitudes of the parietal occipital regions associated with the N400.

	Left Hemisphere	Right Hemisphere
Large Changes (15-20%)	-1.66(1.76)	-3.29(1.81)
Small Changes (5-10%)	-2.65(2.14)	-.75(1.58)

Table Notes:

N200

For the N200, a hemisphere (2 – left or right) x percentage change (2- small or large) repeated measures ANOVA was conducted upon the data for the parietal occipital region. Results revealed no significant main effects of hemisphere, $F(1,14)=1.239$, $p=.284$, *partial* $\eta^2=.081$, and no significant main effects of percentage change, $F(1,14)=.151$, $p=.703$, *partial* $\eta^2=.011$. No interaction was found between the hemisphere and percentage change, $F(1,14)=.809$, $p=.384$, *partial* $\eta^2=.055$. Please see Table 7.6. for the means and standard deviations of the mean amplitudes associated with each condition.

N400

For the N400, a hemisphere (2 – left or right) x percentage change (2 - small or large) repeated measures ANOVA was conducted upon the data for the frontal region.

Results revealed no significant main effects of hemisphere, $F(1,14)=.060$, $p=.810$, *partial* $\eta^2=.004$. A significant main effects of percentage change was found, $F(1,14)=11.385$, $p=.004$, *partial* $\eta^2=.458$. The larger changes were shown to have a more negative mean amplitude of -2.479 (SD = 2.13) compared to the mean amplitude of the smaller changes of -1.702 (SD=1.76). Please see Table 7.7. for the means and standard deviations of the mean amplitudes associated with each condition.

A significant interaction was found between the hemisphere and percentage change, $F(1,14)=59.748$, $p<.001$, *partial* $\eta^2=.810$.

Paired samples t-tests were conducted on the data to look at the hemispheric differences of the large and small changes. It appears that the interaction is coming from the direction of these differences. With the small changes, there was a significant difference between the left hemisphere (MV = -2.65, SD=.71) and the right hemisphere (MV = -.75, SD=.46), $t(14)=-3.059$, $p = .008$, with the left hemisphere demonstrating the larger negative mean amplitude. With the large changes, the direction of this difference was the opposite with the left hemisphere showing a less negative mean amplitude of -1.661 compared to the more negative right hemisphere (MV = *-3.29, SD=1.67)*, $t(14)=2.984$, $p= .010$. Please see Figure 7.8., below, for a graphical representation of this interaction.

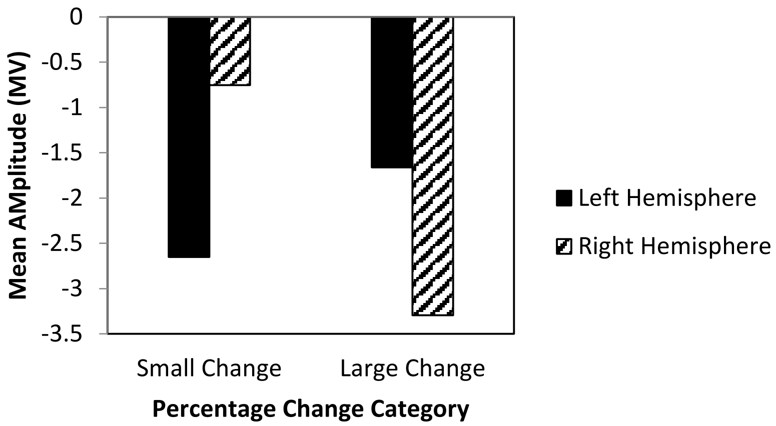

Figure 7.8. The interaction between hemisphere and the percentage change category of the N400 frontal brain region.

7.6.3.4 Comparison of Quantitative Arrays 4 and 6, and Qualitative Small and Large Changes

For this section, analyses were conducted on the regions of interest for the N400 and N200 ERP components. The comparison was made between array sizes 4 and 6 of the quantitative task and the smaller and larger changes of the qualitative task.

<u>N200</u>

For the N200, a comparison was made between the qualitative and quantitative change detection tasks with regards to the parietal occipital region.

For this section, the quantitative task was separated into two types – array size 4and array size 6. The qualitative task was also separated into two types of large changes and small changes. This means that results are presented as four separate task types.

Table 7.8. Means and standard deviations of the mean amplitudes of the N200 within each condition of the parietal occipital region.

	Quantitative Array Size 4	Quantitative Array Size 6	Qualitative Small Change	Qualitative Large Change
Left Hemisphere	-2.49(1.75)	-2.24(1.6)	-.79(1.37)	-.37(1.14)
Right Hemisphere	-1.82(2.11)	-1.87(2.71)	-.002(1.34)	-.17(2.11)

Table Notes:

A task (4) x hemisphere (2) repeated measures ANOVA was conducted on the data.

Results demonstrated a significant main effect of task type, $F(3,11)=10.657$, $p=.001$, *partial* $\eta^2=.744$. Bonferroni post hoc analyses demonstrated that the qualitative small-change task had a smaller mean amplitude of -.396 (SD=1.34) compared to both the quantitative array size 4 task with a mean amplitude of -2.161 SD=1.45, p=.001) and also the quantitative array size 6 task with a mean amplitude of -2.061 (SD= 2.19, p=.007). The qualitative large-change task was also shown to have a smaller mean amplitude of -.273 (SD=1.15) compared to the quantitative array size 4 task with a mean amplitude of -2.161 SD=1.45, p<.001). This indicates that both qualitative tasks have smaller mean amplitudes compared to the quantitative tasks.

No main effects of hemisphere were found, $F(1,13)=.859$, $p=.371$, *partial* $\eta^2=.062$. The interaction between task type and hemisphere was also found to be not significant, $F(3,11)=.739$, $p=.551$, *partial* $\eta^2=.168$.

N400

For the N400, a comparison was made between the qualitative and quantitative change detection tasks with regards to the frontal region. A task (4) x hemisphere (2) repeated measures ANOVA was conducted on the data.

Table 7.9. Means and standard deviations of the mean amplitudes of the N400 within each condition of the frontal region.

	Quantitative Array Size 4	Quantitative Array Size 6	Qualitative Small Change	Qualitative Large Change
Left Hemisphere	-.33(2.52)	-1.06(1.72)	-2.37(1.91)	-1.49(1.70)
Right Hemisphere	-2.35(3.4)	-1.05(3.12)	-.86(1.58)	-3.36(1.86)

Table Notes:

Results demonstrated a significant main effect of task type, $F(3,11)=5.274$, $p=.017$, *partial* $\eta^2=.590$. Bonferroni post hoc analyses demonstrated that the qualitative small-change task had a significantly smaller amplitude of -1.616 (SD=1.74) compared to the qualitative large-change with a mean amplitude of -2.432 SD=1.78, p=.027). The qualitative small-change task was shown to have a significantly larger mean amplitude compared to the quantitative array size 6 task which had a mean amplitude of -1.063 (SD=2.41, p=.026).

There were no main effects of hemisphere found, $F(1,13)=1.011$, $p=.333$, *partial* $\eta^2=.072$.

An interaction effect was found between the task type and hemisphere, $F(3,11)=17.489$, $p<.001$, partial $\eta^2=.827$. Paired samples t-tests were conducted on the data. Significant differences were found between the hemispheres of the qualitative small-change task, $t(14)=-3.059$, $p=.008$, with the left hemisphere having a more negative mean amplitude of -2.6515 (SD=1.96) compared to the mean amplitude of the right hemisphere of -.7533 (SD=1.84).

Similar to this, a significant difference was found between the hemispheres of the qualitative large-change task, *t(14)=2.984, p=.010,* with the right hemisphere having a more negative mean amplitude of -3.295 (SD=2.45) compared to the mean amplitude of the left hemisphere with a mean amplitude of -1.661 (SD=1.79)

In contrast to this, there were no significant differences between the hemispheres of the quantitative array size 4 task, *t(14)=1.734, p=.105* and there were no significant differences between the hemispheres of the quantitative array size 6 task, *t(14)=.054, p=.957*.

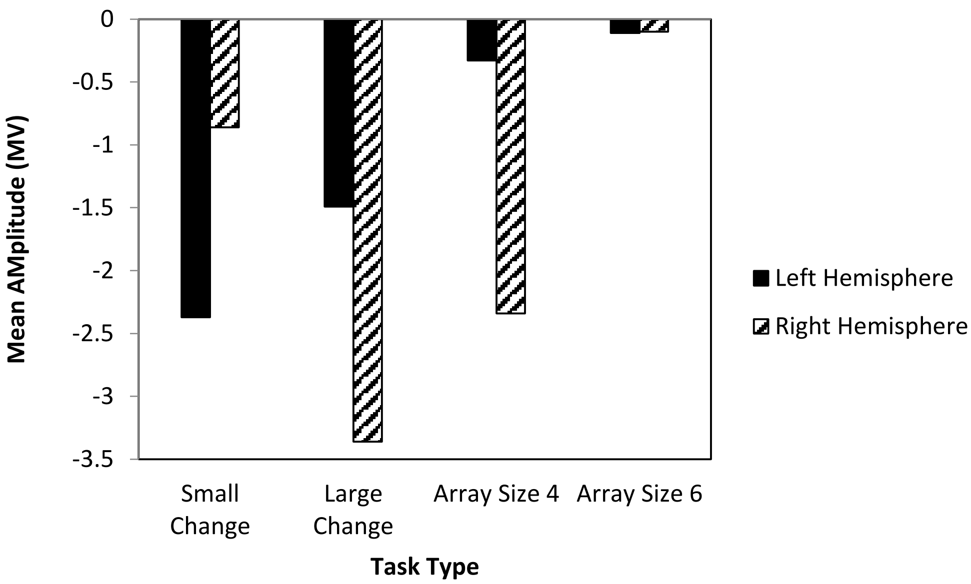

Figure 7.9. The interaction between task type and hemisphere for the N400 within the frontal brain region.

The interaction is appearing from the differences in the hemisphere mean amplitudes of the quantitative and qualitative change detection tasks. Please see Figure 7.9. for a representation of this interaction.

7.7 Discussion

The aim of the current investigation was to record electrophysiological data in order to try and provide evidence towards potential semantic involvement in both a quantitative and a qualitative change detection task. The visual specific N200, verbal semantic related N400 and the attentional marker of the P300 were all recorded to try and provide evidence for either a domain specific approach or multicomponent approach to the functional working memory architecture of these tasks.

Although it was predicted that there would be array size differences between the array size 4 and array size 6 of the quantitative task for the N200 amplitude and latency, this was shown to not be the case. No array differences were found with regards to the mean amplitude or the peak latency of the array sizes 1 and 2 of the qualitative change detection task or array sizes 4 and 6 of the quantitative change detection task, supporting prediction 2, suggesting that both array sizes would have similar N400 and N200 amplitudes. The current results demonstrated that the qualitative change detection task produced larger negative deflections for both the N200 and N400, initially opposing prediction 3 of the current chapter which predicted that the quantitative change detection task would have larger negative deflections of the N400 and N200. Although no predictions were made about the P300 component, the current results demonstrated a larger P300 amplitude in relation to the quantitative change detection task, suggesting the use of greater attentional control resources with the completion of this task. After initial analyses took place, a further qualitative percentage change analysis looked at any potential N400 and N200 differences of the smaller and larger shape changes of the qualitative task, similar to that of the dual task analyses in chapter 6. It was demonstrated that the larger changes presented a more negative mean amplitude of the N400, thus indicating the greater presence of semantics within the larger size changes. No mean amplitude differences were found when looking at the N200 in the smaller and larger size changes.

The results of the current investigation cannot readily be explained using that of Senkowshi and Herrmann (2002) or Berti et al. (2000) who proposed the N200 as a marker of task complexity and also as a marker of increased visual load with greater array sizes.

With regards to the current study, the research from Berti et al. (2000) and Senkowshi and Herrmann (2002) would have suggested array size 6 to have the largest N200 compared to the array size 4 of the quantitative task; however, results were not in this direction as no array size differences were found within either the quantitative or qualitative change detection tasks. From this, it can be suggested that the current N200 amplitudes are not simply due to task complexity alone and that other cognitive factors may have an influence upon the N200 amplitudes.

The larger N200 amplitude for the qualitative change detection task could be explained by the research of Nobre et al. (1998), indicating differences in attentional control between the tasks. Nobre et al. (1998) had suggested that the N200 was related to attentional control by demonstrating a larger N200 with a task that required greater attentional control between different cognitive functions such as the perception of colours and words. As the qualitative change detection task required the encoding of two different shapes, colours and sizes within memory, and not just the simple square colours as in the quantitative task, then this could contribute to the increased N200 amplitude with regards to the qualitative task. The use of greater attentional control may have been needed to store both colours and shape sizes in memory, unlike just colour features of the quantitative change detection task. Alternatively, the requirement for the encoding and subsequent maintenance of the precise size of memory stimuli may have required greater attentional control.

However the lack of array size differences does contrast with the findings of Nobre et al. (1998) as this piece of research would have suggested greater attentional control for array size 6, for example, greater attentional control may have been needed to encode more colours within memory. As there were no array size differences within the current change detection protocols, it can be suggested that the differences in attentional control lie solely within the different types of tasks (encoding of colour and shape compared to colour only), and potentially not in an increase of the amount of information to be remembered.

Current results do support the research of Morgan et al. (2010) who found that the N200 was greatest over the parietal occipital electrodes (PO7 and PO8), in particular when participants completed a single task relating to colour. The parietal and occipital regions make up the key visual cortex brain areas (Bergmann, Genç, Kohler, Singer & Pearson, 2014) therefore the high activation of the N200 within this region has indicated visual resource use in both change detection tasks. Morgan et al. (2010) suggested that the N200 may have been colour processing specific, however this was not shown within the current results as the larger N200 amplitude was presented for the qualitative change detection task which assessed the sizes of different shapes.

However, the measurement of the N200 was compared in two different situations within the current study and the study from Morgan et al. (2010). Morgan et al. (2010) had used both colour and spatial location in one task to show that the N200 had a larger amplitude in relation to colour. The current investigation used colour and shape in an attempt to find differences. If the current investigation has used all black shapes in the qualitative task, for example, then there may have been larger differences between the N200 in the qualitative and quantitative tasks as the N200 was suggested to be colour specific by Morgan et al. (2010).

With reference to the potential use of binding of colour and shape in the qualitative change detection task, this could have been one reason for the larger N200 of the qualitative tasks. As the binding of features occur in memory, processes of binding and retrieval may occur with deeper processing than just simple recognition and storage processes. During this task, it means that participants have to pay attention to two visual features instead of just the only colour feature. The N200 could have simply been larger for the qualitative task due to the potential use of deeper processing during the binding of colour and shape (Wheeler & Treisman, 2002). In a piece of research using a neurological methodology from Parra, Della Sala, Logie and Morcom (2014), it was suggested that parietal brain regions are active during the binding of shape and colour. In support of this, the current thesis demonstrated that the N200 showed a greater negative deflection within the parietal region, again indicating the potential use of binding processes in the qualitative task. To investigate this further, the current ERP methodology could be used in change detection tasks where different types of binding are present, for example colour and shape, (Baddeley, Allen & Hitch, 2011) or colour and location (Jackson, Morgan, Shapiro, Mohr & Linden, 2011). This could give further explanations of why the N200 was larger for the qualitative task, and whether binding could account for these differences.

The next stage of the analysis looked at the potential use of verbal or semantic information within the change detection tasks by recording the verbally related N400. For this component, it was again predicted that the N400 would be larger for the quantitative tasks, indicting the more use of verbal information as in studies 2 and 4 of the current doctoral thesis. The initial analyses were opposite to this as a larger N400 was produced for the qualitative change detection task. Further change size specific analyses revealed that the source of this enhanced N400 component was within the larger, 15-20%, shape changes of the qualitative task, thus mimicking the greater semantic interference effects upon the larger change stimuli found in the previous chapter.

Neumann and Schweinberger (2008) and Eimer (2000) demonstrated a larger N400 for the repetitions of famous faces, indicating that this component can be semantically related; therefore the current larger amplitude for the qualitative task could indicate the greater use of semantics within qualitative change detection task trials where large changes occurred. A difference in brain region was found between the current study and Neumann and Schweinberger (2008) when an area of interest was highlighted. The current study found the greatest activation of the N400 to be at the frontal electrodes whereas greatest activation was found at the parietal electrodes for Neumann and Schweinberger (2008). The activation of the frontal electrodes in the current investigation provides evidence towards a less visual specific approach to the representations used by change detection tasks. Parietal occipital electrodes could have had heightened activation of the N200 due to their links with the visual cortical regions associated with visual working memory (Bergmann et al., 2014) and the activation of the frontal electrodes from the N400 could have suggested the links to semantic involvement from aspects of long term memory (Riby & Orme, 2013), providing evidence towards a more multicomponent approach to the functional working memory architecture of these tasks.

In a less visual piece of research, Nittono, Suehiro and Hori (2002) looked at an increased N400 in relation to word imagine ability. Both high and low imagery words elicited a larger N400 compared to the words which could not have any form of imaginable representation. Because of Nittono et al. (2002) results, the current study could have suggested a larger N400 with regards to the quantitative change detection tasks. The coloured squares presented, although randomly ordered, could have been grouped into meaningful images into memory.

For example, a square array consisting of a red, white, blue and yellow square could have been memorised by recalling the colours of the Great Britain flag. The qualitative task has less opportunity to do so as only shape size was being measured and only three different colours were present. However, as the quantitative task did not produce a more negative N400, this cannot be a reason as to why results were presented as they were.

In a similar suggestion from the results of Riby and Orme (2013), the current study predicted that the quantitative task would have a larger N400 compared to the qualitative tasks. It was expected that a larger N400 would be apparent, just as with the potentially quantitative matrix patterns test in that of Riby and Orme (2013). Although the quantitative task in the current study did not present a greater N400 amplitude, results from the current investigation have extended that of Riby and Orme (2013), by suggesting that the N400 activation may not be quantitative task specific. For the current results the use of semantics was present in both the quantitative and qualitative tasks; however, an increase of the use of semantics was shown in the large change qualitative task, extending the use of semantics to change detection protocols as well as the Visual Patterns Test used by Riby and Orme (2013). The regions of highest activation for both the N200 and N400 were found to be similar to that of Riby and Orme (2013), indicating that the brain activity during visual working memory protocols may be similar across different task contexts. Riby and Orme (2013) suggested the frontal region to have heightened activation during the N400 and the parietal occipital regions to show heightened activation during the N200. Similar results were found with the current investigation and have indicated that the use of both regions may indicate a less visual specific approach to such visual memory tasks.

In contrast to Riby and Orme (2013), Du, Zhang and Zhang (2014) suggested that a visual Chinese word recognition task would only activate the N200 as these types of tasks do not include semantic processing. The results from the current change detection investigation, whilst being in support of Riby and Orme (2013), are in contrast with that of Du, et al. (2014) in suggesting that a visual task may elicit some form of semantic recruitment. The N200 was activated during the presentation of visual array in the current investigation, providing evidence which suggests that the N200 may also be active during tasks where verbal semantics are present. Du et al. (2014) gave the indication that the N200 could only be activated in the case of early visual processing. Although the current results have demonstrated that the N200 could be linked to early visual processing, there is no evidence towards the N200 being active when the N400 is not present.

The final component which was recorded during the current investigation was the P300. Due to analysis of this component being suggested as an exploratory analysis, a prediction was not made. Results demonstrated that overall, the quantitative change detection tasks produced a larger positive deflection of the P300 compared to the qualitative tasks, indicating that this task may make use of greater attentional control resources.

Lavric, Forstmeier and Rippon (2000) suggested that a greater activation of the P300 could be caused by differences in working memory involvement within different types of tasks and this could also be the case for the current investigation. Lavric et al. (2000) demonstrated greater P300 amplitude when a task was using both visual and verbal working memory functions within the task. Although presentation differences were present between the current working memory tasks and the analytical task used by Lavric et al. (2000), for example the current task was a change detection task but the analytical task was not as such, the activation of the P300 during the quantitative task could give suggestions of the use of verbal working memory and visual working memory within the quantitative and qualitative change detection protocols. However, one qualifier to this is that the P300 analyses were not carried out contrasting the small and large qualitative changes.

The results of the current investigation demonstrated a clear difference between the P300 of the quantitative tasks (using array sizes 4 and 6) and the qualitative tasks (which used array sizes 1 and 2). Morgan et al. (2008) suggested that an increased P300 could be associated with information load. In the case of the current doctoral thesis, array sizes of 4 and 6 do have a higher information load compared to array sizes 1 and 2, therefore the current results could be explained by the differences in information load between the quantitative and qualitative change detection task. However, if information load was the only explanation for such differences then the P300 amplitude would have differed between array sizes 4 and 6 due to the differences in information load. As this was not the case, results cannot be attributed to information load alone. Explanations such as the allocation of attention as discussed by Poich (2007) could be discussed, who suggested that participants needed a greater focus of attention for tasks where a larger amount of information is stored. Once participants have reached working memory capacity of 3-4 items, greater attentional control is needed to keep these items in memory and to not confuse the items with previously displayed ones. As array sizes 1 and 2 in the qualitative task are below the capacity limit of 3-4 items, further attentional resources may not have been needed to successfully store these items within visual working memory, indicating a decreased P300 amplitude. The array size of 6 however is above the capacity limit of 3-4 items, and greater attentional control mechanisms may have been needed to control the use of the visual and verbal information used during the encoding of this array size.

With regards to the overall aim of the current doctoral thesis, to discover whether both change detection tasks could be seen as visual domain specific (Baddeley, 2012) or more multicomponent (Logie, 2011), it can be suggested that this electrophysiological data provides evidence towards the more multicomponent approach to the functional working memory architecture (see Brown and Wesley, 2013; Logie, 2011). The results of the current experiment demonstrated activations within the parietal-occipital region which has been highly associated with early visual processing (Bergmann et al., 2014). However, the activation in the frontal brain regions alongside the parietal-occipital activations suggests a more multicomponent approach to change detection tasks. Frontal regions have been associated with long-term memory and episodic semantic memory (Hsieh & Ranganath, 2014; Riby & Orme, 2013) indicating that both change detection tasks may not have been using visual only information. Again, a qualifier is that the N400 was significantly reduced in the small qualitative change trials.

Improvements and Future Research

There are three main factors which could have affected results and may need to be adjusted should a replication of this study occur. The qualitative change detection task which assesses size changes in visual arrays also included the colours of the shapes. As Morgan et al. (2010) suggested that components like the N200 could be colour specific, a repetition of this investigation could see the qualitative encoding shapes displayed in only one colour and in a potentially neutral colour such as black. This would provide evidence towards whether the N200 is colour specific as greater differences may be apparent if the colour of the shapes is more neural within the qualitative change detection task. The use of one square, such as that of Phillips and Hamilton (2001) could also be a suggestion for a change in the current qualitative investigation as this would reduce any effects that colour had upon the detection of size changes in visual arrays.

Similar to the suggestions made regarding the percentage changes of the qualitative task used in the dual task procedures of chapter 6, the use of both larger and smaller changes in the current qualitative task is one which needs considering. As the current results, in particular, indicated a greater use of semantics within the qualitative large changes compared to the smaller changes, this allows researchers to question to future use of such large changes in visual arrays. The use of 30 smaller changes and 30 larger changes in each qualitative array size, and finding a greater N400 with regards to the larger changes, could imply that the larger changes are what have caused the qualitative task to overall demonstrate a larger N400 in comparison to the quantitative task. In future, the use of more smaller change sizes and fewer larger changes may mean that results are changed if the smaller changes do not produce such a negative N400. This implication will also be discussed further within Chapter 9 of the thesis when looking towards future use of the task.

An alternative method to investigate the brain regions associated with each change detection task could be to use an fMRI approach. Research from Bergmann et al. (2014) used an fMRI approach to show which brain areas were associated with a Gabor visual memory task. Within this research, the primary visual cortex was investigated, including areas V1, V2 and V3. Although the current ERP methodology gave current research researchers an indication of where the brain activity was associated with each task (for example which electrodes had the highest activation), it did not look in depth at the brain regions associated with the primary visual cortex. Comparison could be made between the quantitative and qualitative change detection task in relation to the V1, V2 and V3 brain areas. As the V1 area is the most visually related visual cortex location, activation of this area would demonstrate the use of visual information with a certain task. However, if the V3 area is activated, then this could indicate more spatial information use (or less visual specific information use) which could provide current researchers with further evidence towards the domain specific or multicomponent nature of change detection tasks. Using specific ERP components can only provide basic ‘on-the-scalp’ suggestions as to why one component may have more negative mean amplitudes than the other as this technique only uses the electrical activity associated with the scalp area of the head. An fMRI method, however, could look at the whole brain in terms of the size of the brain areas associated with visual memory as previous researchers such as Emrich, Riggall, LaRocque and Postle (2013) have done.

As with the previous qualitative change detection task in chapter 6 of the current thesis, the current task also caused participants to use binding processes. When participants had to recall the size of the shape, they had to ensure that the colour of the shape was the same and participants were not aware that the colour of the shape would not be different here. Larger N200 amplitudes could have been produced for the qualitative change detection task due to the increased use of feature binding within this task (see Brown & Brockmole, 2010; Wheeler & Treisman, 2002). Although this task was originally created to assess size changes in different shapes, researchers used coloured shapes which unintentionally encouraged the participants to use a feature binding method to aid memory recall. Research using a neurological methodology from Parra et al. (2014) suggested that parietal brain regions are active during the binding of shape and colour and this could have had an effect upon the current ERP results. To investigate this further, the current ERP methodology could be used in change detection tasks where different types of binding are present, for example colour and shape, (Baddeley et al., 2011) or colour and location (Jackson et al., 2011). This could give further explanations of why the N200 was larger for the qualitative task, and whether binding could account for these differences.

As this study was not independent of the thesis, researchers had to ensure that the tasks were the same as the change detection tasks used in the previous thesis experimental investigations. Both the quantitative and qualitative tasks had to use the same array sizes as studies 2 and 4 of the current doctoral thesis so that a comparison could be made and conclusions could be made across all investigations. To make a greater comparison, it would be interesting to record electrophysiological data whilst participants were completing the interference paradigms of studies 2 and 4 as the N200 and N400 could be recorded to clarify whether these interference tasks are visuospatial and verbal in nature. This would give a clearer indication of whether the interference paradigms chosen were appropriate enough to hit the specific working memory components within the working memory architecture and could give a clearer definition of the brain areas being activated by the tasks.

7.8 Chapter Summary

The current chapter has investigated the electrophysiological properties of the brain in relation to the quantitative and qualitative change detection tasks. Both the N200 and N400 were activated for both change detection task, however greater negative deflections were present in the qualitative task, suggesting the extensive use of visual and verbal information and resources in the large change size trials. However, the attentionally related P300 had indicted a larger positive deflection within the quantitative task, suggesting a greater use of attentional resources for this task. This could be due to this task using larger array sizes than the qualitative task

The final stage of the current thesis is to use the change detection tasks and associated knowledge to utilise the tasks real life context. In this case, a developmental context will be chosen as this context has particular links between working memory capacity and intelligence. In an attempt to predict verbal and non-verbal intelligence using the quantitative and qualitative change detection task, any links with intelligence will help in providing evidence towards either a domain specific or domain general resource demand within visual change detection protocols. The next chapter in the thesis (chapter 8) will discuss the research associated with working memory capacity and intelligence, and will also detail the final study of the thesis where the change detection tasks are used with children ages 7-8 and 10-11 and 12-13 years.

CHAPTER 8

Developmental Investigation –Working memory and intelligence

8.1 Chapter Overview

Chapter 5 and 6 demonstrated how two visual change detection tasks, a quantitative task and a qualitative task, could use verbal representations or semantics with the collection of dual task behavioural data. Chapter 7 then used electrophysiological data collection methods to support previous findings from chapters 5 and 6, where the data provided suggestions that these visual memory tasks may not be as visual specific as Luck and Vogel (2013) initially thought. In the current chapter, the findings about these two change detection tasks will now be applied to a developmental context in an attempt to provide further evidence for the differential use of both visual and verbal semantic representation within the change detection task performance. By using these tasks in an attempt to predict both verbal and non-verbal intelligence, it can be shown whether these tasks are more multicomponent or domain specific in nature within child as well as adult contexts.

8.2 Background

8.2.1 Defining Intelligence

Working memory capacity is thought to have strong links to intelligence (Carpenter, Just and Shell, 1990; Just and Carpenter 1992). There are two types of intelligence that have so far been defined in the literature. Horn and Cattell (1966) gave two early definitions of Crystallised Intelligence and Fluid Intelligence. Crystallised Intelligence was suggested to be the type of intelligence which is gained from experience and knowledge. This can come from education or real life experiences, meaning we have knowledge of previous events. Fluid Intelligence, however, was suggested to be the type of intelligence that involved no previous knowledge. Examples include identifying patterns and problem solving tasks which are aspects of intelligence which can be measured without any previous knowledge or experience.

8.2.2 Adult Work

Kyllonen and Christal (1990) investigated the link between working memory capacity and intelligence in an adult population. They defined intelligence as 'reasoning ability – general fluid intelligence' and used several mathematical, verbal and diagram tasks to assess reasoning. These types of measures are fluid measures only. Researchers concluded that working memory capacity and reasoning abilities are strongly correlated ($r = .80$ and $r = .90$), however there are other factors, such as processing speed which could influence this link.

In a later review, Conway, Kane and Engle (2003) suggested that the links between working memory (capacity) and intelligence are due to factors such as the ability to control attention. These researchers suggested that working memory capacity and intelligence were not identical in nature, but did have similar underlying processes such as paying attention to goal relevant details. The suggestions were similar to that of the previous research from Engle et al. (1999) who also proposed that the link between working memory and intelligence is due to the ability to direct attention to the different tasks. Colom et al. (2005) suggested that working memory has a stronger link to intelligence measures (compared to short-term memory) due to the similarities of both processing and storage abilities of working memory and potential intelligence tasks. As short term memory does not necessarily include advanced processing abilities, this does not have a strong link to intelligence.

Research by Unsworth and colleagues (Unsworth et al., 2014; Unsworth & Spillers, 2010) suggested that the link between working memory and intelligence could be due to individual differences in attentional control. Attentional control is needed during the completion of a task so that the participant can actively maintain information in memory even when external and internal distractions are present. Using a variety of working memory span tasks, working memory capacity tasks, attentional control tasks, secondary memory tasks and tasks to measure intelligence (defined as general fluid intelligence), it was also suggested that the links between working memory and intelligence could exist as both can rely on secondary memory retrieval abilities. Finally, the relationship between working memory and intelligence has been suggested to be mediated by a participants working memory capacity (Cowan et al., 2005; Unsworth et al., 2014). Conclusions were made suggesting that working memory and intelligence are both distinct abilities; however, they have links to attentional control processes, capacity and secondary memory abilities which can underly the relationship between the two.

A very relevant piece of research to the current doctoral thesis comes from Fukuda, et al. (2010). Within this paper, a question was raised as to what aspect of working memory capacity links with fluid intelligence, for example, the amount of information stored or the resolution of these stored representations. This investigation was one of the first to use tasks which assessed both the quantitative and qualitative aspects of working memory capacity in regards to how the link to intelligence. By using a young adult population, an exploratory factor analysis demonstrated that the relationship between working memory capacity and fluid intelligence is mediated by the amount of information stored ($r=.66$) and not by the resolution of the stored items ($r = -.05$). Fukuda et al. (2010) used Ravens Advanced Progressive Matrices and Cattell’s Culture Fair Test as intelligence measures with a change detection task as the capacity measure. Large changes in the stimuli arrays were used to assess the quantitative measure of working memory capacity and small changes in the stimuli were used to assess the qualitative measure.

Similar to Fukuda et al. (2010), Shipstead and Yonehiro (2016) looked at the links between visuospatial working memory and reasoning measures. However, in their investigation, both domain-specific and domain-general relationships were investigated, with conclusions being made regarding the domain-general nature of these links. Shipstead and Yonehiro (2016) used visual change detection paradigms and verbal memory span tasks to look at the relationships between these types of tasks and both verbal reasoning (nonsense syllogisms) and non-verbal reasoning (Raven's Progressive Matrices). After showing that the verbal memory tasks and visuospatial working memory had strong positive correlations, confirmatory factor analyses were conducted and concluded that visuospatial working memory has very strong links to reasoning ability, no matter what type of reasoning ability this may be. Shipstead and Yonehiro (2016) concluded that a domain-general approach to the links between visuospatial working memory and reasoning ability could be adopted, with the domain-general explanation being in the form of a general executive attentional resource. It was proposed that this resource can then be supported by the more domain-specific processes which can be used during long memory delays and interference. This piece of research emphasises the importance of both modality general and modality specific working memory processes in the relationship with intelligence.

The current doctoral thesis will conduct a similar investigation to that of Shipstead and Yonehiro (2016) but by using both large-change and small-change types of stimuli as discussed in Fukuda et al. (2010). It was noted that the quantitative and qualitative measures of Fukuda et al. (2010) were very similar, for example including the same shapes and this could have caused problems as participants may have repeatedly viewed the stimuli. The current doctoral thesis will therefore use two separate tasks consisting of two different capacity measures. The quantitative change detection task will look at large, categorical colour changes in visual arrays and the qualitative change detection task will look at the smaller size changes in visual arrays to stop any confusion to participants.

8.2.3 Child Work

Gathercole and Pickering (2000) suggested that by looking at a child's working memory development in their early years then any potential deficits in academic achievement could be highlighted due to the similarities between the working memory abilities and academic abilities (intelligence measures). These similarities included factors such as processing abilities; memory performance and reasoning measure performance which are all abilities used in both working memory tasks and academic performance tasks. Building upon this, Gathercole, Pickering, Ambridge and Wearing (2004) investigated the structure of the working memory architecture in children ages from 4 to 15 years of age. A battery of memory tests, including a VPT and recall tests were given to the children which were designed to assess the specific working memory components within the architecture. Gathercole et al. (2004) suggested that from the age of 6 years old, a clear modular structure could be seen within the working memory architecture of the children indicating three distinct components, - one resembling the Phonological Loop, the VSSP and also a Central Executive component, meaning that this piece of research has been highly influential in the area of developmental working memory. By showing that children as young as 6 could use different components within their verbal and visual memory, it has given a direction for the research, suggesting that both the Phonological Loop and VSSP may be separate components and may need to be studied separately in relation to intelligence. The current doctoral research will aim to explore this further using the working memory capacity of a child participant as a predictor of their intelligence scores in an attempt to look at the structure of the working memory architecture.

An example of the research, which has used working memory capacity measures in children, has come from Riggs et al. (2006) who investigated the working memory of 5 to 10 year olds, specifically focusing upon changes in the working memory capacity of visual information. This research used an adaptation of Luck and Vogel's (1997) change detection task in which 1, 2, 3, 4, and 5 coloured squares were shown to the children. Riggs et al. (2006) used this paradigm as previous research from Ross-Sheehy, Oakes and Luck (2003) had used this task in a young infant context, therefore it had been successfully employed using children much younger than 5 years old.

The differences in working memory capacity at the ages of 5 and 10 years old were discussed in terms of attentional lapses. At 5 years old, it may be difficult from a child to pay attention to a task for a long length of time whereas a 10-year-old may find this not a difficult task due to their ability to focus their attention to the task. A suggestion was made stating that the older children may have used verbal strategies to enhance their visual memory, however this was only a suggestion from Riggs et al. (2006) and future research is therefore needed.

In a similar piece of work, Riggs, Simpson and Potts (2011) studies the working memory of children aged 7, 10 with a comparison to an adult sample, focussing upon the memory for multi feature objects. Single versus multiple probes were used in this investigation with the use of 2, 4 or 6 coloured and orientated bars.

It was shown that, as expected, the children at 7 years old found the tasks difficult and had the largest decline in memory performance. Riggs et al. (2011) suggested that the development of processing speed could be a great influence on the memory of children and adults. As children, at the age of 7, have not fully developed their processing speed abilities, they therefore take longer to complete a task. The attentional control approach of Cowan et al. (2005) was suggested as a reason for the differences in performance between children and adults, similar to that of the earlier adult work of Engle et al. (1999). At 7 years old, the children have not fully developed a comprehensive scope of attention; therefore, working memory capacity may be limited to only 1 or 2 items – not as comprehensive as the 3 to 4 items that adults can hold in memory at one time. As the adults develop the ability to store more information, their Control of Attention becomes greater and their ability to complete memory tasks becomes more successful. Similar suggestions were made from Cowan, AuBuchon, Cilchrist, Ricker and Scott Saults (2011) who suggested that the differences in working memory at the ages of 6-8 and 11-13 were not based solely on encoding limitations but in fact the ability to control attention within a task.

Hamilton (2013) discussed developmental trends with regards to both quantitative measures of working memory (Visual Patterns Test and Corsi Blocks) and also qualitative measures of working memory, proposing a developmental fractionation as age increases. In his 2011 work, Hamilton suggested that the qualitative measures of working memory capacity rely heavily upon the visualization of the material presented at high quality (fidelity) representations which are perceptually driven. As a result of this, it was suggested that the use of long term memory or semantics could not be used in an effective manner to support the memory representations used within qualitative memory tasks in particular, supporting the suggestions made by the later work of Brown and Wesley (2013) with regards to qualitative visuospatial task representations.

Work from Cowan, Fristoe, Elliott, Brunner and Scott Saults (2006) investigated working memory and its links to intelligence, in particular the two components of Cowan's (2001) attentional control model – the Scope of Attention and Control of Attention. In this piece of research, 52 children and 52 college students took part in an original change detection task created by Luck and Vogel (1997), an auditory digit span task, visual letter span task and a dual modality memory task. As a measurement of intelligence, subsets of scales were taken from the Stanford-Binet Intelligence Scale (Thorndike, Hagen & Sattler, 1986). Correlational analyses were conducted between all measures finding a strong correlation between general fluid intelligence (Stanford-Binet Intelligence Scale) and in particular the visual task array task. Cowan et al. (2006) demonstrated a developmental trend proposing differences between adult and children capacity scores. It was concluded that at age 10-11 years, working memory capacity is still developing due to the development of the attentional control systems within memory. Adults can store information within the Scope of Attention and transfer this information to the Control of Attention where this information can be manipulated and used at a much later time – children are just developing this ability therefore working memory capacity scores tend to be lower than adults at aged 10. Similar suggestions were also made by Fry and Hale (1996) and Fry and Hale (2000) who indicated that developmental differences may be present in the development of memory and processing abilities. Because intelligence can be linked of such processing abilities (namely processing speed), if processing speed has not fully developed in childhood then intelligence and reasoning abilities may also not be fully developed.

Research from, Engel de Abreu, Conway and Gathercole (2010), discussed the links between working memory and fluid intelligence in children ages 5 to 9 years old, using short-term memory as a variable which could influence this relationship. Ravens Coloured Progressive Matrices (1995) was given to the children to assess non-verbal reasoning abilities which were defined as the intelligence measures in this case. Amongst the measures given, digit recall tasks assessed short-term memory and counting recall tasks assessed working memory.

Results revealed significant correlations between working memory measures and Ravens Coloured Progressive Matrices (r = .19 to .34). A discussion was made regarding the distinction of intelligence, working memory and short-term memory. Engel de Abreu et al. (2010) suggested that although each of these constructs are separate in adults, in children this distinction is not so prominent as the relationships between all three constructs demonstrated shared variance between all variables. Any links between working memory, short-term memory and intelligence could be due to the fact that these abilities in children are still developing and that the abilities of each measurement have not been fully developed differentiated even at the age of 9.

Research from Heyes, Zokaei, van der Staaij, Bays and Husain (2012) is one of the most recent and pertinent research articles to detail the relationship between working memory and intelligence. Of particular interest was the investigation of how the resolution of items can link to intelligence instead of the more common number aspect (Cowan et al., 2006). A method was chosen which consisted of a bar rotations task where the child participants were presented with three simultaneous bars. It was then required for participants to move a final bar into the same positon as a previously shown one. As a measure of intelligence, standardised yearly SAT scores were used to produce Full Scale IQ scores for each child. This meant that standardised intelligence measures could be taken for all of the children involved which were ages 7 to 13 years. A strong positive relationship between the bar rotation task scores and the intelligence measure was found, suggesting that both tasks may share similar processing abilities. The main finding of this research was that the precision of bar rotation develops through childhood and this development was suggested to be not due to a decrease in memory errors such as mis-binding. This research supports the findings of change detection paradigm development research from Riggs et al. (2006) and Cowan et al.

(2006) who suggested that working memory capacity can improve with age. More critically it suggested that in children, a qualitative change detection task could predict reasoning ability, unlike the adult pattern found by Fukuda et al. (2010)

8.3 Rationale for study 6

The aim of the current study is to investigate the relationship between visual working memory capacity and intelligence, using both a verbal and non-verbal measure of intelligence. Firstly, it was decided to look at working memory, as previous research had shown links between working memory and fluid intelligence, and not between short-term memory and fluid intelligence (Kyllonen and Christal, 1990; Colom et al., 2005; Colom et al., 2008).

The research aimed to investigate the differences between quantitative and qualitative measures of visual working memory as Hamilton (2013) had proposed developmental differences between younger and older participants within their research.

Fukuda et al. (2010) highlighted the importance of using quantitative stimuli in relation to intelligence proposing links specifically between a quantitative measure and non-verbal intelligence. Heyes et al. (2012), however, demonstrated the importance of the relationship between qualitative stimuli and intelligence measures using intelligence measures such as scholastic achievement scores and full scale IQ scores. Thus, the major aim of this chapter is to identify the extent to which there is a relationship between the quantitative and qualitative change detection tasks and verbal and nonverbal ability task performance in children. This should cast light on the domain general and domain specific characteristics of the two tasks. By employing the two change detection tasks that have been used for the duration of the current doctoral thesis the current developmental investigation will provide an opportunity for coverging methods to reveal the domain specific and multicomponent demands of the two tasks. If non-verbal ability performance can be predicted by either task, then this would have implications for domain general resource use by the task. The change detection tasks will be modified to be more appropriate for each age range of the developmental context. Array size 1 only will be used for the qualitative size change detection task, and then an appropriate sample of the array sizes 1, 2, 4 and 6 for the quantitative colour change detection task.

The Wechsler Abbreviated Scale of Intelligence, second edition (WASI-II, 2011) has been chosen as this was the most appropriate version of the Wechsler Abbreviated Scale of Intelligence (originally created in 1999) and is a short intelligence test to administer for the developmental population. This measure is being used for this investigation as researchers are concerned with both visual and verbal measures of intelligence and measures such as Ravens Progressive Matrices (1938), updated from Raven, Court and Raven (1985), would not be suitable due to the lack of verbal intelligence subsets within the scale. Although the Ravens tests have been shown to have high reliability statistics of Cronbachs Alpha 0.93 (Schweizer, Goldhammer, Rauch and Moosbrugger, 2007), the subsets within these sets of tasks include task that are visuospatial in nature. Rao & Baddeley (2013) proposed no links with any types of verbal reasoning abilities in adults with these measures.

In the sorter version of a Wechsler Abbreviated Scale of Intelligence (2011), testing takes approximately 30 minutes for the four sub-scale version of the task, or approximately 15 minutes for the two sub-scale version of the task (Irby & Floyd, 2013). In the four sub-scale version, participants are given four short tasks which include a vocabulary and a similarities task for the verbal measures. Non-verbal measures contain block design and a matrix task. The two sub-scale measure includes the vocabulary task and a matrix task. Ganivez, Konold, Collins and Wilson (2009) demonstrated that the WASI had very high construct validity. It was shown that each verbal reasoning task and non-verbal reasoning task each loaded onto the appropriate verbal/non-verbal construct during correlational analyses meaning each subset measures a different intelligence component (verbal or non-verbal).

For the current PhD Thesis, the two-scale version of this task will be used (matrix reasoning task and a vocabulary reasoning task) instead of the four-scale version as this is a shorter version of the task and it is hoped that the children will be more focussed within the short time frame.

The estimated administration time of the Wechsler Abbreviated Scale of Intelligence, second edition, was suggested to only be approximately 15 minutes. The Wechsler Intelligence Scale for Children (1949, 2003), which is the full scale version of the child intelligence test, could take up to an hour to administer and could potentially cause fatigue effects within the current investigation, therefore this will not be used.

8.4 Predictions

These predictions are based upon the results of studies 2, 4 and 5 of the current doctoral thesis.

1) The quantitative change detection task score will significantly predict both verbal and non-verbal ability.
2) The qualitative change detection task score will only predict non-verbal ability; it is also predicted that this will not significantly predict performance on the verbal ability task.

8.5 Method

8.5.1 Design

A non-experimental design was employed, with age and the two change detection measures as the predictor variables, and vocabulary and matrix reasoning as the criterion variables.

8.5.2 Participants

Overall 90 children aged 7-13 years took part in the investigation. All schools within the area of Sunderland, Newcastle-upon-Tyne, Washington and Hartlepool were invited to take part in the investigation, with three schools offering to take part. One secondary school from Southampton volunteered to take part after viewing an advertisement about the study.

27 children in year 8 took part (12 males, 15 females). They had a mean age of 12.74 and a standard deviation of .45.

33 children in year 6 took part (13 males, 20 females). They had a mean age of 10.09 and a standard deviation of .291.

30 children in year 3 took part (14 males, 16 females). They had a mean age of 7.13 and a standard deviation of .345.

8.5.3 Materials

8.5.3.1 Memory Tasks

The quantitative and qualitative change detection tasks were taken from studies 2 and 4 of the current doctoral thesis. Please see chapter 5, Figure 5.1., for further information regarding the quantitative tasks and chapter 6, Figure 6.1., for information regarding the qualitative tasks.

The quantitative change detection tasks required participants to identify whether a coloured square was the same or different as in a previous encoding array shown. With the work of Cowan et al. (2005) and Riggs et al., (2006) in mind, these arrays consisted of either 4 or 6 for the year 8 children, 2 or 4 squares for year 6 children, and 1 and 2 squares for the year 3 children. As these tasks had been adapted for a younger sample compared to the previous doctoral studies, the response buttons on the keyboard were changed to colours instead of letters. The child had to respond by pressing a green coloured button indicating the ‘same’ colour detection and a red button indicating the ‘different’ colour detection. The qualitative change detection tasks required participants to identify whether a shape was bigger or smaller than the corresponding one in the previous encoding array shown. In this case, the encoding shape arrays consisted of only 1 shape for all years. The child had to respond by pressing a green coloured button indicating the ‘smaller’ size change detection and a red button indicating the ‘larger’ size change detection

8.5.3.2 Intelligence Measures

Wechsler’s Abbreviated Scale of Intelligence – second edition (2011) was chosen as the intelligence measure. This measure consisted of both a verbal and non-verbal tasks. The verbal task was named as ‘Vocabulary’. In this task, participants were verbally presented with words and images and had to describe what each item was. This subset has 31 items, 3 of which are pictures and 28 are words. For the children aged 7-8, the researcher is to not display the stimulus book during the presentation of the verbal words. For the children aged 10-11 and 12-13, the researcher states the word verbally and also points to the word in the stimulus book. Participants were scored on how well they described the visual and verbal items. A basic response of describing what the word does (but not stating what the object is) would score 0. Stating what the object is but not elaborating would score 1 and giving a more detailed explanation of the object, for example, what the object is used for, would score 2. Items ranged from easy, such as fish (visual image) and car (verbal word) to more difficult such as Scallop (visual image) and entertain (verbal word). When participants scored three incorrect consecutively or when the child had completed all necessary items, the testing session ended.

The non-verbal task was known as ‘Matrix Patterns’. In this task participants were shown a pattern of images and had to decide which smaller image was the correct one to complete the larger pattern. Matrix patterns ranged from easier patterns, such as different types of fruit, and then finished with more difficult patterns, such as complex shapes. A score of 1 was given for a correct answer and a score of 0 was given for an incorrect answer. When participants scored three incorrect consecutively or when all necessary items had been completed, the testing session ended.

8.5.3.3 Scoring of the WASI-II

Scoring of the WASI-II was explained in the Manual (Wechsler, 2011). Raw scores were taken from each participant and were converted to K scores (for the quantitative task). All scores were then transformed into Z scores ready for the analysis procedure and these z sores were standardised to the whole sample of age (not individual age groups). Please see the results section of the current chapter for details on this.

8.5.4 Procedure

The current investigation was ethically approved by the University Health and Life Sciences Ethics Committee. Initially, all primary schools across Sunderland, Newcastle-upon-Tyne, Hartlepool and Washington were contacted through email with an invitation to take part in the research. At this point, four schools replied to the email, volunteered and the researcher met with each head teacher to discuss the practical side of conducting the research. One secondary school outside of the North East (in Hampshire) also volunteered to take part in the

research. An initial consent form was signed by each head teacher to display that permission was given to send information to parents regarding the study aims and tasks.
Two weeks before the research began; information sheets and consent forms were distributed to parents so that the researcher had full consent before using any child in the study.

On testing days, each child participant was sat in a quiet area so that no disruptions were apparent. The researcher explained that there would be four different types tasks to complete *(a quantitative and qualitative memory task plus the two Wechsler subsets)* and gave details of the child information sheet to the child participant. At this point, the child was asked to sign the consent form and was reminded that they could stop at any time.

Before each task, the researcher explained the task to each child participant using a PowerPoint presentation (for the memory tasks) or the examples from the Wechsler Manual (for the intelligence tasks). Pease see Appendix F for examples of these instructions. All tasks were then given, in a random order so that fatigue effects and practice effects could be reduced.
Once all tasks had been completed, a debriefing sheet was given to the child participant and the researcher also explained verbally why the research was being carried out. Each child was thanked for their time of for taking part in the study and was told that they could ask for their scores not to be used if this was wanted.
After testing had finished in each school, parents were sent the debriefing sheets which included the aims of the study, contact details of the researcher and also the right to withdraw their child's data.

8.6 Results

For the purposes of the current analysis, the scores for both quantitative change detection tasks were averaged so that only one quantitative score was used for each participant. These were then transformed into K scores (please see Table 8.2., below). As the qualitative change detection task included only array size 1, these scores did not need to be averaged. The collation of the data meant that each participant provided one quantitative change detection score, one qualitative change detection score, a verbal intelligence score (vocabulary task), a non-verbal intelligence score (matrix task) and a full scale IQ score. Please see Table 8.1. for the means and standard deviations of each task.

Table 8.1. Raw scores of the change detection conditions and the reasoning (intelligence) measures.

	Quantitative Raw	Qualitative Raw	Vocabulary Raw	Matrix Raw
Year 3	15.35(2.14)	14.26(2.97)	17.26(2.84)	13.30(1.82)
Year 6	15.74(1.86)	16.24(2.53)	28.69(2.51)	17.09(2.62)
Year 8	15.54(2.00)	15.68(2.88)	25.48(6.60)	16.13(3.32)

Table Notes: For the quantitative score, averages were taken of both array sizes used.

8.6.1 ANOVA Analyses of Change Detection Protocols

Performance on the Quantitative change detection task was measured using the K score formula of Cowan et al. (2005). Please see chapter 3 for details of this formula using the single probe formula. As the k scores are measured differently to the raw scores of the Qualitative change detection task, these scores have then been standardised using a z-score calculation of $\mathbf{z=(x - M)/\sigma}$, where ‘x’ is the raw score, ‘M’ is the sample mean and ‘σ’ is the sample standard deviation. The means and standard deviations of these Z scores can be seen in Table 8.2., below.

Table 8.2. Means and standard deviations of the Raw scores of the qualitative change detection measure, k scores of the quantitative measure and z scores of both change detection measures.

	Quantitative K score	Qualitative Raw Score	Quantitative Z score	Qualitative Z score
Year 3	1.27(.47)	14.26(2.97)	-.887(.36)	-.491(1.03)
Year 6	2.52(.86)	16.24(2.53)	.064(.65)	.196(.88)
Year 8	3.63(1.30)	15.68(2.65)	.908(.99)	.305(.92)

Table Notes:

A 3(year group – 3, 6 or 8) x 2(task type – quantitative or qualitative) Mixed ANOVA was conducted on the Z score data. Results demonstrated no effects associated with the task type ($F(1, 87) = 0.038$, $p = .846$, $\eta p^2 = .000$). However, a main effect associated with age was found ($F(2, 87) = 36.212$, $p < .001$, $\eta p^2 = .454$). Bonferroni post hoc analysis revealed that all calculated z scores for each age group were significantly different to each other (all $p<.01$). The year 8 children were shown to have a larger z scores compared to those of the year 3 and 6 children. Please see Table 8.2. for means and standard deviations of each age group.

An interaction effect between age and the task type was also found ($F(2, 87) = 5.344$, $p = .006$, $\eta p^2 = .109$). Paired samples t-tests on the year 3, 6 and 8 change detection task scores indicate that this interaction effect is coming from the significant difference between the quantitative and qualitative task of the year 8 data, $t(26)= -2.462$, $p= .021$. Please see figure 8.1. as a visual representation of this interaction.

A significant difference was found between the quantitative and qualitative task scores of the year 3 data, *t(29) = 2.266, p = .031*. However, the direction of this difference was different for the year 3 and year 8 data causing the interaction. Within the year 3 data, the qualitative task had a smaller z score of -.491 (SD=1.03) compared to the quantitative task of -.877 (SD=.36). In contrast to this, within the year 8 data, the quantitative task had a smaller z score of .064 (SD=.65) compared to the qualitative task of .196 (SD=.88), indicating opposing trends within the year 3 and year 6 data. No significant differences were found between the quantitative and qualitative task scores of the year 6 data, *t(32)=.584, p= .563*. Please see Figures 8.1. and 8.2. for a comparison between the current results and the results discussed by Hamilton (2013).

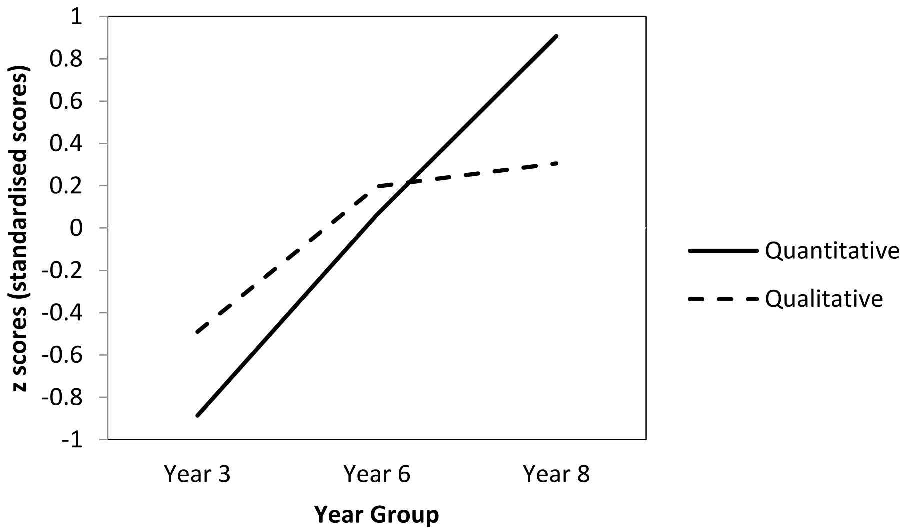

Figure 8.1. Interaction between age group and task type to show the developmental data trends.

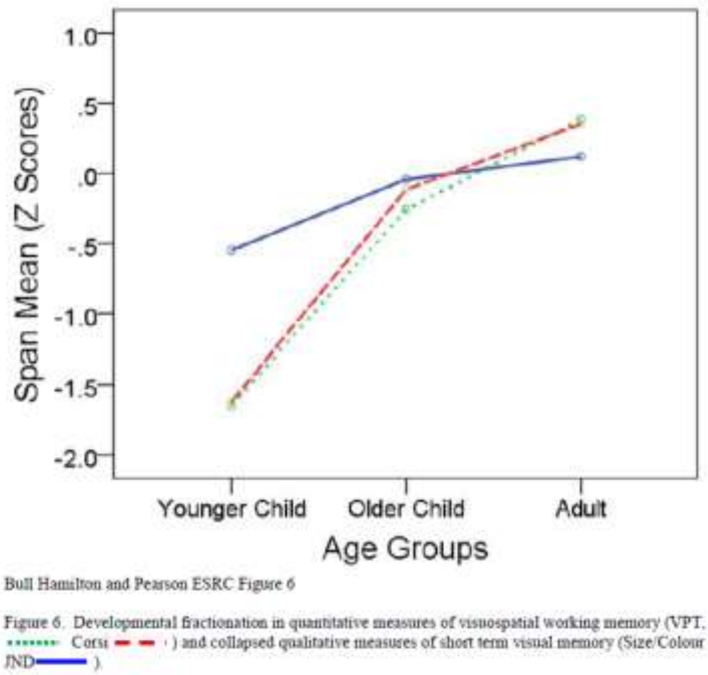

Figure 8.2. The developmental trends discussed by Hamilton (2013) showing differences between child and adult age groups of quantitative (Corsi, VPT) and qualitative (Size JND) task performance.

8.6.2 Regression Analyses

Six hierarchical regressions were run using the standardised z scores of the quantitative task, qualitative task, vocabulary task and the matrix task. These regressions looked at whether the quantitative and qualitative change detection tasks could predict verbal and non-verbal intelligence, but also whether they could predict the full scale IQ score of the combined intelligence measures. Within each regression, model one contained only age as the predictor. Model two contained both age and the appropriate change detection task measure as the predictors. Please see Table 8.3., below, for the z scores of all intelligence and capacity measures.

Table 8.3. Means and standard deviations of the z scores for the quantitative and qualitative change detection tasks, matrix task, vocabulary task and a full scale IQ score.

	Quantitative z score	Qualitative z score	Vocabulary z Score	Matrix z Score	FSIQ z Score
Year 3	-.887(.36)	-.491(1.03)	-1.244(.43)	-.852(.55)	-1.04(.4)
Year 6	.064(.65)	.196(.88)	.485(.38)	.288(.79)	.387(.37)
Year 8	.908(.99)	.305(.92)	.789(.55)	.595(1.00)	.692(.64)

Table Notes:

Regressions

Table 8.4. Regression statistics for regression 1 (Do age and the quantitative task predict full scale IQ?).

	B	***T***	***Β***	***R***	***R^2***	***ΔR^2***
Model 1				.803	.664	.640
Age	.314	12.618***	.803			
Model 2				.804	.646	.638
Age	.296	8.506***	.756			
Qualitative	.060	.754	.067			

Note: age+quant = FSIQ, *p<.05, **p<.01, ***P<.001

The first regression attempted to identify whether age and the quantitative change detection task could predict the full scale IQ score. In this regression, however, the contribution of the quantitative change detection task in model two was found to be not significant ($F_{change}(1,87)= .568, p=.453, R^2_{change} = .002$). This indicated that the quantitative change detection task did not predict full scale IQ beyond the significant predictor of age. Please see Table 8.4. for the beta weights for this model.

Table 8.5. Regression statistics for regression 2 (Do age and the quantitative task predict non-verbal intelligence?).

	B	***T***	***Β***	***R***	***R²***	***ΔR²***
Model 1				.594	.353	.345
Age	.261	6.923***	.594			
Model 2				.594	.353	.338
Age	.260	4.913***	.591			
Qualitative	.004	.037	.004			

Note: age+quant = matrix, *p<.05, **p<.01, ***P<.001

The second regression attempted to identify whether age and the quantitative change detection task could predict non-verbal intelligence (matrix task). In this regression, however, the contribution of the quantitative change detection task to model two was found to be not significant ($F_{change}(1,87) = .001, p=.970, R^2_{change} < .001$). This indicated that the quantitative change detection task did not predict non-verbal intelligence beyond the signifncant predictor of age. Please see Table 8.5. for the beta weights for this model.

Table 8.6. Regression statistics for regression 3 (Do age and the quantitative task predict verbal intelligence?).

	B	***T***	***B***	***R***	***R^2***	***ΔR^2***
Model 1				.836	.699	.695
Age	.368	14.282***	.836			
Model 2				.840	.705	.699
Age	.332	9.319***	.756			
Quantitative	.115	1.416	.115			

Note: age+quant = vocab, *p<.05, **p<.01, ***P<.001

The third regression attempted to identify whether age and the quantitative change detection task could predict verbal intelligence (vocabulary task). In this regression, however, the contribution of the quantitative change detection task to model two was found to be not significant ($F_{change}(1.87) =2.006$ $R^2_{change} <.007, p=.160$). This indicated that the quantitative change detection task does not predict verbal intelligence beyond the significant predictor of age. Please see Table 8.6. for the beta weights for this model.

Table 8.7. Regression statistics for regression 4 (Do age and the qualitative task predict full scale IQ?).

	B	*T*	*Β*	*R*	R^2	ΔR^2
Model 1				.803	.644	.640
Age	.314	12.618***	.803			
Model 2				.818	.699	.662
Age	.292	11.373***	.745			
Quantitative	.150	2.573*	.169			

Note: age+qual = FSIQ, *p<.05, **p<.01, ***P<.001

The fourth regression attempted to identify whether age and the qualitative change detection task could predict full scale IQ With this regression, model two was found to be significant $F(2, 89) = 87.998, P<.001$, *Adjusted* $R^2=.662$, with both age and the qualitative change detection task being found to predict full scale IQ. 66.2% of the variance within the model can be accounted by the age and qualitative task. The unique variance of the qualitative change detection task was shown to be $F_{change}(1,87) = 6.621, p=.012, R^2_{change} = .025$ (2.5%). Table 8.7. demonstrates that the Standardised Beta weights are positive for both age (.745) and the qualitative task (.169) indicating a positive relationship between the full scale IQ score and the predictors. The higher participants scored on the qualitative task then the higher their full scale IQ score was.

Table 8.8. Regression statistics for regression 5 (Do age and the qualitative task predict non-verbal intelligence?).

	B	***T***	***Β***	***R***	***R²***	***ΔR²***
Model 1				.594	.353	.345
Age	.261	6.923***	.594			
Model 2				.660	.435	.422
Age	.216	5.725***	.490			
Qualitative	.353	3.566**	.305			

Note: age+quanl = matrix, *p<.05, **p<.01, ***P<.001

The fifth regression attempted to identify whether age and the qualitative change detection task could predict non-verbal intelligence (matrix task). With this regression, model two was found to be significant $F(2, 89) = 33.512, P<.001, Adjusted\ R^2=.422$, with both age and the qualitative change detection task being found to predict non-verbal intelligence. 44.2% of the variance within the model can be accounted by the age and qualitative task. The unique variance of the qualitative change detection task was shown to be significant, $F_{Change}(1,87) = 12.720, p<.001, R^2_{change} = .083$ (8.3%). Table 8.8. demonstrates that the Standardised Beta weights are positive for both age (.490) and the qualitative task (.385) indicating a positive relationship between the matrix raw score and the predictors. The higher participants scored on the qualitative task then the higher their matrix task score was.

Table 8.9. Regression statistics for regression 6 (Do age and the qualitative task predict verbal intelligence?).

	B	***T***	***B***	***R***	***R²***	***ΔR²***
Model 1				.836	.699	.695
Age	.368	14.282***	.836			
Model 2				.836	.699	.692
Age	.368	13.388***	.838			
Qualitative	-.005	-.080	-.005			

Note: age+quanl = matrix, *p<.05, **p<.01, ***P<.001

The sixth regression attempted to identify whether age and the qualitative change detection task could predict verbal intelligence (vocabulary task). In this regression, however, the contribution of the qualitative change detection task to model two was found to be not significant ($F_{change}(1,87) = .006\ R^2_{change} < .007,\ p=.936$). This indicated that the quantitative change detection task did not predict verbal intelligence beyond the significant predictor of age. Please see Table 8.9. for the beta weights for this model.

8.6.3 Correlations

Bivariate correlations were conducted between the five main variables within the current investigation. These included the z scores for the working memory capacity measures (quantitative and qualitative change detection tasks), the z scores for the two intelligence measures (matrix reasoning task and the vocabulary reasoning tasks) and also the z scores for the full scale IQ scores.

Table 8.10. Partial correlations between the Z scores for the working memory capacity measures and intelligence measures for all children, controlling for the age of the child.

	1	2	3	4
1. Matrix Task				
2. Vocabulary Task	.205			
3. Quantitative Task	.004	.150		
4. Qualitative Task	.357***	-.009	-.018	
5. Full Scale IQ Score	.863***	.671***	.081	.266*

Table Notes: *p<.05, ** p<.01, *** p<.001

Significant positive correlations, as presented in Table 8.10., were found between the qualitative task and the matrix task ($r = .351$, $p=.001$), the full scale IQ score and the matrix task ($r = .863$, $p <.001$), the full scale IQ score and the vocabulary task ($r = .671$, $p <.001$), and the qualitative task and full scale IQ score ($r = .266$, $p = .012$). These correlations support the previous regression analysis showing links between the qualitative task and the full scale IQ score and the qualitative task and matrix task.

8.7 Discussion

The aim of the current investigation was to look at the links between working memory capacity and intelligence in children and to discover if any developmental differences in task performance were present between the year 3, year 6 and year 8 data sets, similar to that found by Hamilton (2013). The study aimed to discover if the quantitative and qualitative change detection tasks, which were constructed in chapters 5 and 6 of the thesis, could be found to predict verbal and non-verbal intelligence. Predictions were made stating that only the quantitative task would be able to predict verbal and non-verbal intelligence due to the more domain general resource demands observed in the dual task procedures of from chapter 5 and 6 and N400 obsrevations in chapter 7 of the current doctoral thesis.

The two change detection tasks were utilised in a developmental context using children aged 7-13 years. This was due to previous research using similar methods (Riggs et al., 2006) and suggesting that change detection tasks were appropriate to assess visual working memory capacity of children within this age limit. Wechsler's Abbreviated Scale of Intelligence (2011) was used, instead of more exclusively visual based intelligence measures such as Ravens Advanced Progressive Matrices.

Results from the current investigation produced 2 main findings, one with regards to developmental fractionation of quantitative and qualitative task and the second with regards to whether working memory capacity can predict intelligence. Initial analyses indicated to researchers with the suggestion that main effects of age were present within the data as well as an interaction between age and the memory task type (quantitative and qualitative). At the younger ages of 7-8 years, the children have a more negative z score, indicating lower change detection scores compared to the older children. These scores can interact with the task type, and at the ages of 7-8, the quantitative change detection is less accurately performed than the qualitative task. At the older age range of 12-13 years, results contrast this, with more accurate (and larger) scores of the quantitative task than the qualitative memory task. Final percentage change analysis indicated that all children performed lower on the smaller changes in the visual arrays, indicating that this could have an impact on how the tasks are utilised in future investigations.

Regression analyses looked at the types of ability/intelligence which could be predicted and indicated that the quantitative change detection task was unable to predict any form of intelligence whether this be verbal or non-verbal in nature. The qualitative change detection task, however, had the ability to predict the non-verbal intelligence measures and also the full scale IQ measures, however no predictions of verbal intelligence were found.

Correlations were then used to look at the relationships between the working memory capacity measures and the intelligence measures, producing significant positive correlations between the qualitative change detection task and the matrix reason task, plus a positive correlation between the qualitative change detection task and the full scale IQ measure, supporting the findings of the regression analyses. These correlations support the significant regression models regarding the qualitative change detection protocol.

Hamilton (2013) suggested a pattern of developmental fraction between the quantitative and qualitative tasks in the age range present in this study. At the older ages of an adult population, the trends within the quantitative and qualitative task scores differ, with the adults having more accurate performance on the quantitative tasks (Corsi Blocks, VPT) compared to the qualitative task (Size JND). Similarly, the current developmental results indicate similar findings with the older age group of 12-13 years presenting similar data trends as the adult group of the work discussed in Hamilton (2013). In his chapter, Hamilton (2013) discussed how the research of Hamilton (2011) argued that qualitative tasks such as the Size JND or bar rotation tasks used by Heyes et al. (2012) require high fidelity representations which are derived from visual cognitive processes. As a result, these tasks are less likely to be supported by verbal representations or long term memory semantics. The current developmental data, and regression analyses have provided support for this. As the qualitative change detection task was successfully able to predict the matrix task score (non-verbal intelligence measure) but not the vocabulary task score (verbal measure), this emphasises the visual nature of such qualitative tasks.

Results of the current investigation do not support that those of Fukuda et al. (2010). Fukuda et al. (2010) demonstrated that quantitative aspects of working memory capacity were more strongly linked to intelligence measures than qualitative measures. Fukuda et al. (2010) used Ravens Progressive Matrices and the Cattell Culture Fair Test as measurements of intelligence which are both seen as non-verbal measurements of intelligence. The current study, however found the opposite, with no successful predictions of this nature. The qualitative change detection task was found to predict non-verbal intelligence whereas the quantitative task was found to not predict any form of intelligence, contradicting the findings of Fukuda et al. (2010). Although the non-verbal subset of the Wechsler Abbreviated Scale of Intelligence (2011) is of a similar nature to that of Ravens Progressive Matrices, no links were found between the quantitative change detection task and non-verbal ability in the current investigation.

The research from Fukuda et al. (2010) employed an adult participant sample whereas the current study attempted to extend these findings by using a child participant sample. It could be suggested that within the child population, the working memory architecture and attentional control mechanisms (Cowan et al., 2005; Engle et al., 1999) of these children are still developing and therefore links between quantitative measures and non-verbal intelligence could not be found. Riggs et al. (2006) suggested that children as young as 10 can have a capacity limit of 3-4 items just as high as the adult population does which Fukuda et al. (2010) would suggest to be the main reason for the link between quantitative measures and non-verbal ability.

As the current investigation used both 7-8 year olds and 10-11 year olds and 12-13 year olds, it was also found understandably that age was an important factor in predicting intelligence in children. The older year groups may have had a more stable working memory capacity than the younger children (as suggested by Riggs et al., 2006), allowing their qualitative visual working memory capacity to be able to predict intelligence more accurately. To investigate these links further, it may be an advantage to use the current two change detection tasks and intelligence measures within an adult population to look at any possible differences between the 10-11 year olds and an adult population. This would also give a clear replication of the current investigation within an adult context.

In line with Heyes et al. (2012) the current research found the qualitative change detection task to have links to intelligence in young children, in particular the prediction of the full scale IQ measure and the non-verbal intelligence measure. As Heyes et al. (2012) used a completely different qualitative task to the current investigation, it could be suggested that children can store fine detailed representations, as proposed by the Shared Resource Model (Bays et al., 2009). The storage of these fine details could define how intelligence tasks are completed. If the children are capable of storing fine details in a memory task then they may also be able to store fine details produced by the matrix task, demonstrating how the links could be present between the two measures.

Fry and Hale (1996) suggested that working memory capacity and intelligence link due to the similar processes involved when completing each task, such as visual processing ability. Results of the current developmental investigation could support this, in particular in relation to the qualitative change detection task. The qualitative change detection task involves the memory of fine detailed shapes within memory and the matrix reasoning (intelligence) task also involves the processing of detail. The lack of links between the quantitative measure and the matrix task could indicate that the precision of a representation is an important factor in the link between working memory capacity and intelligence instead of the amount of objects stored alone. During the quantitative change detection task, participants simply have to attend to colour only and not the fine details of the images, meaning that their processing ability does not have to be as efficient as with the qualitative change detection task. In children, it could simply not be about the amount of information that is stored in memory, which shows a link to intelligence, but the fine detail of the stored information and potentially the processing which occurs with these fine details. In their later work, Fry and Hale (2000) suggested that developmental differences may be present due to the still developing concept of processing speed at the younger ages. This difference in processing speed could be an explanation for the results of the current research. As the younger children (7-8 years) may still be developing their processing speed, the developmental differences within the data may be present as the younger children may have limited processing abilities to support the completion of the task.

Kyllonen and Christal (1990) suggested that the major link between working memory and intelligence was the processing speed of the information. Those who had quicker and more efficient processing abilities could complete complex span procedures. It was proposed that the links between working memory and intelligence measures was not simply due to the working memory capacity of the person alone (also suggested earlier by Cowan et al., 2006) but also the ability to maintain active representations within memory whilst simultaneously encoding further information. These links between working memory capacity and intelligence measures could be a reason as to why the qualitative change detection task was able to predict verbal and non-verbal intelligence measures whereas the quantitative change detection task could not. During the quantitative change detection task, participants simply have to attend and store one array of items at a time, without any large previous trial interference effects, meaning only basic processing abilities may be needed. In the qualitative change detection task however, participants are required to hold such information within memory but this task also requires various other information processing abilities such as the potential processing of both different colours and shapes.

As the verbal reasoning measure requires the ability to remember information potentially stored in long term memory (for example, when describing an object), participants must have the ability to access these long term memory storages and must also have the ability to store recently presented matrix pattern information in memory within a similar time frame. As Kyllonen and Christal (1990) suggested that the links between working memory capacity and intelligence were not due to capacity alone, this explains the lack of links between the quantitative change detection task and also the non-verbal and verbal intelligence measures.

Gathercole and Pickering (2000) suggested that the links between working memory capacity and intelligence were there due to the fact that most non-verbal measures included the use of the VSSP. The current investigation has extended this by also suggesting the use of an Episodic Buffer or Central Executive component as suggested by Hamilton (2013), particularly highlighting this with the qualitative change detection task (due to the prediction of the full scale IQ measure). If a change detection task has the ability to predict verbal intelligence as well as non-verbal intelligence, then these connections within the working memory architecture cannot be attributed to the VSSP alone. There needs to be some way of integrating the visual and verbal information use, and this is where an Episodic Buffer or Central Executive component could be useful to create a more multicomponent approach to working memory as proposed by Logie (2011).

Improvements and Future Research

Although the current investigation had planned on using array size 2 within the qualitative change detection task, initial procedures of the study highlighted that the younger children could not complete this task due to its difficulty. As a result, array size 2 was taken out of the year 6 data and was also not implemented in the procedure of the ear 8 data and meant that researchers had to then standardise the working memory capacity scores. Future investigations may be beneficial focussing upon the storage of multiple qualitative items to discover if any further developmental differences are resent within the data as shown with array size one in the current results and those discussed by Hamilton (2013).

Similar to the suggestions made from the dual task investigations in chapters 5 and 6, future work with the current qualitative change detection task may need to consider the amount of small and large changes used with the qualitative change detection stimuli. As the participants may have been performing more accurately on the larger changes, this could give a false indication that the current qualitative task has used the most appropriate size changes for the purposes of the investigation. Using smaller changes in the task may make the cognitive demands more difficult; however, the task may then be seen more as a qualitative task which assesses smaller changes in visual arrays. Although the larger changes increased performance o the task, it can be suggested that this is due to the quantitative nature of this type of stimuli which may be susceptible to elements of verbal strategy use, similar to that of Brown and Wesley (2013). Further investigations will need to be conducted upon the use of smaller changes only within a developmental context to provide support for these suggestions.

The results of the current investigation could be used to prompt training within a developmental-educational setting in future as research such as Klingberg et al. (2005) and

Jaeggi et al., (2008) have done in both adult and child contexts. If a child's verbal and non-verbal intelligence is tested throughout their primary school education, then any occurrences of 'low' intelligence scores could prompt training using the quantitative and qualitative change detection tasks.

The current developmental results can conclude two things with regards to the data presented. Firstly, developmental fractionation was evident in the quantitative and qualitative change detection tasks, providing evidence that the development of these tasks may differ with age, with older children performing more accurately on the tasks compared to the younger children. Thus, the two tasks appear to draw upon discrete processes. Secondly, the lack of links between the quantitative change detection task and both intelligence measures suggests that this task may not be multicomponent in nature with regards to a developmental population and the multicomponent nature of both the quantitative and qualitative change detection tasks may be attributed to the cognitive processing within an adult population alone.

8.8 Chapter Summary

The current chapter has provided a developmental context of which the nature of the representation of the quantitative and qualitative task could be investigated, and in this case to see if the quantitative and qualitative measures could predict verbal and non-verbal intelligence. Results suggested no links between the quantitative change detection protocols and all forms of intelligence, however the qualitative change detection protocol was able to predict both the full scale IQ measure and non-verbal intelligence. Findings suggested a developmental fractionation in relation to the development of quantitative and qualitative memory protocols. Results can suggest that the change detection tasks may only be context dependent with regards to the multicomponent nature of this task. As memory and attentional control are still developing in children, the domain general links may not be present.

The next and final chapter of the current doctoral thesis will bring together the collection of results presented throughout the thesis to will aim come to a final conclusion about each change detection task. Future investigations and improvements to the thesis will also be discussed.

CHAPTER 9

General Discussion

9.1 Chapter Overview

A series of experiments have been carried out and reported in this thesis which have attempted to articulate the nature of representations used by a quantitative and a qualitative change detection task protocol. It was questioned as to whether each task used visual domain specific representations or whether verbal and more multicomponent representations were also used.

The current chapter will give a brief overview of the results of each doctoral study and will discuss which working memory approaches may be most appropriate to explain the representations used during the quantitative and qualitative change detection tasks. Finally, methodological issues will be presented and directions for future research will be given before the final conclusions of the thesis are made.

9.2 Summary of Results

This section aims to give a brief overview of the aims and findings of each study created for the doctoral thesis.

9.2.1 Experiments 1 and 2 (Pilot Investigations)

Experiments 1 and 2 aimed to pilot and introduce the two visual change detection tasks used for the duration of the doctoral thesis. In experiment 1, the quantitative change detection task was piloted, with the consideration of the potential array sizes to be used and also the retrieval contexts to use for the subsequent thesis investigations. The quantitative change detection task was taken from Luck and Vogel (1997) and was adapted to incorporate several array sizes and retrieval conditions. In this pilot experiment, participants had to focus upon encoding arrays, consisting of either 1, 2, 4, 6 or 8 coloured squares. A retrieval (or probe) array was presented, prompting participants to decide if a highlighted square was the same or different colour to the previous one shown. As this investigation looked at whether single or multiple retrieval probes were the most appropriate for the remaining thesis investigations, three different retrieval contexts were used. A full retrieval array with a cued square, a single central square and finally, a single square in one of the possible eight locations were used as the three chosen retrieval contexts to present to participants.

Initial raw score analyses revealed no significant difference between either of the retrieval contexts, however this thesis has adopted a single central retrieval probe protocol due to the contentious background literature in the area of retrieval contexts. Wheeler and Treisman (2002) had discussed that single retrieval probes the most appropriate context to use; therefore, the single central retrieval context was used for the current research as it eliminated any use of spatial memory cues in retrieval and reduced the possibility of semantics in the form of configural cues being employed (Brady & Alvarez, 2011, 2015).

However, analyses of K scores identified larger K scores for the full retrieval probe condition, indicating that there could be some form of spatial advantage with regards to this condition (Brady & Alvarez, 2011, 2015), therefore this condition was not used during the remainder of the thesis and the single central probe condition was used, as discussed above.

It was decided that array sizes 4 and 6 would be used for the remainder of the thesis as results presented ceiling effects as array sizes 1 and 2, and also potential floor effects at array size 8. The array sizes of 4 and 6 were within the performance level of 60-80% which was needed to demonstrate the correct difficulty level of the task. If participants had been given array sizes 1 and 2 then performance may not have differed from 90-100% and the interference procedures implemented after the pilot investigation may not have been able to affect working memory capacity.

Experiment 2 aimed to pilot the qualitative change detection task which focused upon how different sized shapes were remembered. In this task, participants were asked to view an encoding array of 1 or 2 shapes (squares, circles, triangles), and at retrieval, had to decide if a single probe shape presented, was bigger or smaller than the corresponding previous one shown at encoding. This qualitative paradigm was taken from Bae and Flombaum (2013) as this paradigm was very similar to that of the quantitative task in experiment 1 with regards to the creation of the arrays and encoding presentation times. Within this task, size changes of 5%, 10%, 15%, 20% and 25% were used to discover if participants could detect these changes. Results of the qualitative pilot investigation demonstrated that participants could detect all size changes within the shape arrays. However, it was found that participants were performing at approximately 90% during the 25% changes, therefore it was decided that this size change would be removed during the remainder of the thesis experiments to ensure that the task was sufficiently demanding on visual memory. When the 900 millisecond and 4000 millisecond data were compared, no maintenance interval differences were found and overall effects of percentage change were found when the two sets of data were analysed together, again showing ceiling effects of the 25% percentage change.

Experiments 1 and 2 formed the basis for the tasks which were then subsequently used during the remainder of the doctoral thesis – a quantitative change detection task with array sizes 4 and 6 using a single central retrieval context, and also a qualitative change detection task which used 5%. 10%, 15% and 20% size change in shapes.

9.2.2 Experiments 3 and 4 (Quantitative and Qualitative Interference)

The aims of experiments 3 and 4 of the thesis were to form the dual task behavioural responses during the completion of both the quantitative and qualitative change detection tasks. The aim was to investigate impact of attentionally demanding secondary tasks and identify any potential for visual or verbal semantic representation during the primary change detection tasks. This would afford implications as to whether these representations were visual domain specific, as suggested by Baddeley (2012) and Luck and Vogel (2013) or whether a more multicomponent approach (Logie, 2011) could be adopted instead.

In both experiments 3 and 4, dual task paradigms were used to investigate the representation use of these tasks. During the maintenance interval of each primary change detection task (4000ms), a secondary task was added to see if any disruptions were caused to the primary task. A Bar Fit task (Vergauwe et al., 2009) was used as a marker of visuo-spatial information demand and a Verbal Parity Task (Lepine et al., 2005) was used as a marker of verbal resourcesd use. If any secondary task was found to impair the primary task, then this gave indication of the type of information and representation use during each change detection task.

Results of experiment 3, using the quantitative change detection task protocol, suggested the use of both visuospatial and verbal representations. Both the Verbal Parity task and the Bar Fit secondary tasks caused impairments in performance, allowing the suggestion that a more multicomponent approach to representations could be present in this task procedure. The potential use of the Visual Cache, Inner Scribe and Phonological Loop could be suggested with the use of an Episodic Buffer to integrate the visual and verbal information. This proposal was also suggested by Logie (2011) with regards to other types of visual working memory tasks.

Results of experiment 4, using the qualitative change detection task provided slightly different perspectives. A first attempt at this experiment yielded ceiling effects with regards to the Bar Fit task and Verbal Parity task, therefore a modified procedure enabled these two secondary tasks to be increased in difficulty. This was achieved by adding in an extra secondary task item per trial.

When the final attempt had been completed, the results demonstrated that the Verbal Parity task was having an effect on the qualitative primary task, causing impairments. However, a question arose as to whether this interference task was impacting both the larger 15-20% changes and the smaller 5-10% changes. After arranging the data set trials into the smaller (5-10%) and larger (15-20%) JND changes, it was found that the verbal interference was actually only impairing the larger changes in the visual arrays. This has raised questions as to how future qualitative tasks could be created and has suggested that if a task was made using only smaller changes then it may not be impaired when interference tasks were used and thus would preclude the use of verbal semantics.

9.2.3 Experiment 5 – ERP Investigation

Experiment 5 was created to provide another form of data support for the potential use of verbal representations within the quantitative and qualitative change detection tasks. As experiment 4 had provided unexpected results with regards to the interference effects, experiment 5 was created to try and offer further evidence towards the use of verbal representations. In order to see if visual or verbal representations were being used, the N400 ERP component was used as a verbal marker and the N200 was used as a visual marker. The P300 component was also investigated to discover if there were any differences in attentional control between the quantitative and qualitative task. The method of this investigation was taken from Riby and Orme (2013) who had found the use of verbal representation within a different visual task, the VPT.

This electrophysiological investigation required participants having ongoing ERP analysis whilst completing the quantitative and qualitative change detection tasks, with the tasks being randomly ordered so that fatigue effects were eliminated.

The results of experiment 5 suggested three main differences between the quantitative and qualitative change detection tasks. The N400 demonstrated a larger negative deflection for the qualitative change detection task, suggesting the use of greater verbal representations compared to the quantitative task. Analyses on the small and large change stimuli demonstrated a greater negative N400 with the larger 15% and 20% changes in the qualitative arrays, indicating the greater use of semantics within this particular type of protocol. The N200 also demonstrated a larger negative deflection for the qualitative change detection task, suggesting a greater use of visual representations (or processes) within this task compared to the quantitative task. Finally, the P300 demonstrated a larger positive deflection for the quantitative change detection task, suggesting greater attentional control was needed for this task.

It was discovered that both tasks were using visual and verbal representations as each component was activated when participants completed each task, however, the qualitative task demonstrated a stronger use of both types of representations, but more so in large change contexts. This study provided evidence again towards the more multicomponent approach to visual working memory, suggested from the perspectives of Logie (2011). However, again it should be emphasised that in the qualitative change detection task, the size of the change was critical. In small change conditions the N400 was significantly smaller; corroborating what was found in the dual task behavioural results of the previous chapter.

9.2.4 Experiment 6 – Developmental Investigation

Experiment 6 was the final experiment in the doctoral thesis and aimed to apply the knowledge given from experiments 3-5 to a real-life context. This context was chosen to be a developmental context, using children aged 7-13 years, as previous researchers such as Riggs et al. (2006) had used these types of visual memory tasks with children aged 5-10 years.

Previous research from Fukuda et al. (2010) had used change detection tasks within an adult context and had suggested strong links between quantitative change detection measures measures and intelligence. In contrast, investigations from Heyes et al. (2012) suggested that qualitative measures of working memory efficacy also had strong links to intelligence in children. Experiment 6 aimed to discover which type of working memory task protocol had a stronger relationship with intelligence and to discover if any developmental trends in task performance were present, similar to those discussed by Hamilton (2013). The research aimed to discover if the change detection task scores were able to predict verbal and non-verbal intelligence in children aged 7-8, 10-11 and 12-13 years. A quantitative and a qualitative change detection task had never been combined simultaneously within a developmental context, therefore the experiment 6 was hoping to provide novel evidence for the links between working memory capacity and intelligence within the developmental sample. To provide evidence towards the visual domain specific and multicomponent representation question of the thesis, the intelligence measurements were divided into two distinct verbal and non-verbal measurements. Verbal intelligence was assessed using a Wechsler's Abbreviated Scale of Intelligence subscale of a vocabulary task and non-verbal intelligence was measured using the non-verbal subscale of this intelligence measure of a visual matrix task. If the change detection tasks were seen to use verbal representations (as suggested by the previous experiments) then both change detection tasks should be able to predict verbal intelligence within the developmental contact. Full scale IQ scores were also used in the prediction models to see if these could be predicted with each change detection task.

Results of the developmental investigation demonstrated that the qualitative change detection task performance significantly predicted non-verbal intelligence and also full scale IQ, but not the verbal ability performance. The quantitative task did not predict any form of ability measure, raising questions as to whether these types of tasks would be useful within a developmental educational context where the emphasis was upon verbal ability.

Conclusions of the working memory architecture of each task will now be made, focussing upon the representations use during the quantitative and qualitative visual change detection tasks.

9.3 Quantitative Change Detection task – general or specific resource use?

The results of study 3 indicated that both visuospatial and verbal representations were being used during the quantitative change detection task and this was also supported by the findings of the electrophysiological data collected in study 5, with the activation of both the N200 and N400 during the change detection task. The final thesis investigation, which used both change detection tasks in a developmental context, found no links between the quantitative change detection task and any form of reasoning ability.

An overview of these results would indicate that the quantitative change detection task uses multicomponent representations as it has the capability to use both visual and verbal attentional resources during task completion. However, this could be context dependent and may be only applicable to adults. As with the children in study 6 of the current doctoral thesis the quantitative task did not predict either form of intelligence, it could suggest that the working memory architecture and attentional control mechanisms in children aged 7-13 years have not fully developed. The allocation of visual and verbal attentional resource use during visual change detection task performance may also not be developed at this stage, opposing the views of Gathercole et al. (2004). Gathercole et al. (2004) suggested that children aged between 4 and 15 years had three distinct working memory components within the architecture. It could be that the development of an Episodic Buffer component does not occur until early adulthood (over 15 years of age), meaning that children lack control of verbal and visual integration use.

These results could suggest the use of multiple working memory components (Visual Cache, Inner Scribe, and Phonological Loop) with an Episodic Buffer to control the information use between the slave systems, specifically within an adult context only. The use of integrated visual and verbal resources appears to be context dependant, for example, adults may use both types of resouces successfully but the children may only use the resources which are available at the time of task completion.

In light of the theories proposed by both Baddeley (2012) and Logie (2011), it can be concluded that Logie's working memory model is the most appropriate to use when discussing the quantitative change detection task. From the adult interference/dual task investigations, it was clear that visual and verbal information is at use during the maintenance component of the task. This can be explained by the use of an Episodic Buffer component which integrates visual and verbal information during this task. Within this model, all information is passed through the Episodic Buffer before it reaches any of the slave systems (Phonological store and Visual Cache). This means that verbal information could be used by a visual task if this information is being processed at the same time as the visual information within the Episodic Buffer. This is an argument made by Brown and Wesley (2013) with respect to the VPT task when the stimuli are more verbalizable. The use of this visual and verbal representation in the quantitative task was effectively demonstrated with array size 4 when both visual and verbal interference effects were present. With array size 6 however, it can be suggested that as 6 is above the typical capacity limit of 3-4 items (Luck & Vogel, 1997; Cowan 2000), participants could not use visual representors for all items in this array size and therefore were recruiting verbal information as a way of compensating for the lack of visual resources. Although the developmental results of study 6 did not provide evidence for a more multicomponent approach, considerations need to be made regarding the fact that a child's working memory architecture and attentional control mechanisms may still be developing between the ages of 7-13 years.

As the current thesis results are suggested to support Logie's model, they can therefore be said to not support Baddeley's Multi-Component Model. Baddeley (2012) suggested that visual tasks can only use visual information only as this information is sent directly into the more visual components such as the Visuospatial Sketchpad on a perceptual level (a gateway account). The results of the current thesis have shown that this is not the case due to the demand upon verbal resources during the quantitative change detection task. The potential use of an Episodic Buffer, as proposed by Logie, has demonstrated that there is potentially another component at use during the completion of the quantitative change detection task, instead of just the Phonological Loop and the VSSP as proposed by Baddeley. Baddeley (2012) had discussed another component, the Central Executive which allows for the synthesis of visual and verbal information and can assist with attentional control. Despite Baddeley suggesting a more domain specific approach, where visual and verbal information is separate, current results could suggest that a process similar to the Central Executive component could be an explanation for results. If participants were using both visual and verbal information during the quantitative change detection task, then an integrated process such as the Episodic Buffer component could be an explanation of how participants were dividing attention and using both types of information within the same task. However, as Baddeley clearly stated that a visual task must use visual information only, making predominant demands upon the VSSP; this theoretical perspective will not be used to explain the current thesis as the use of visual and verbal information is sent directly into the domain specific working memory components.

In a similar case to Baddeley (2012), the current results can also not be supported by Cowan's Embedded Processes Model alone. Originally, this model suggested that working memory is defined by the amount of activation from long term memory. As the current study used novel stimuli that were created entirely for this thesis, participants had no previous experience with the stimuli and could not form long term representations. A 500 millisecond encoding time was also used as Luck and Vogel (1997) had suggested that this inhibits the use of long term memory within the quantitative change detection task. If a longer encoding time had been used, as with research from Hartshorne (2008) then indeed, the link to long term memory and working memory could be an explanation of results. Cowan's model also does not account for the differences between array sizes 4 and 6 within the quantitative interference paradigm. Cowan's focus of attention has a capacity limit of approximately 4 items (Cowan, 2000) and this model suggests that once this limit is reached, no more items can be remembered in the focus of attention, and then in some manner a novel pattern would have to be represented in partically activated LTM. The current results demonstrated that several participants could store 6 items in memory; therefore, storage was above the capacity of 4 which indicates that the capacity limit of 4 is not a definitive as first suggested. Cowan's model does not give reasons for such occurrences with novel patterns, difficult to activate LTM representations, whereas Logie's model can offer alternative explanations as to why people can store more than 4 items. Logie's model, on the other hand can suggest that the Episodic Buffer has the ability to control the amounts of visual and verbal information which are used during the storage of array sizes 4 and 6. Cowan's account does not readily appear to offer any explanation for the use of verbal information or why more verbal information may have been used during the completion of array size 6.

In a similar way to the model of Cowan (2000), the perspective from Engle et al. (1999) can also not be used to discuss the results of the current doctoral thesis. Engle et al. (1999) highlighted the importance of attentional control within memory and also the importance of the Central Executive's role in maintaining attentional control. In Chapter 1 (Figure 1.6.), it was proposed that visual, spatial and auditory information was maintained within the same memory component and there were no suggestions made regarding the domain specificity of this information. The model from Engle et al. (1999) suggests that all information, no matter whether this is visual or verbal, can be directed through the model in the same way. There is no suggestion of how a less demanding task may use visual only or both visual and verbal representations, therefore this model cannot be used to discuss the current thesis results as the thesis has specifically focused upon the use of domain specific versus multicomponent representations. The model from Logie (2011) could contrast the work of Engle et al. (1999), proposing separate components for each type of representations (visual, verbal, spatial) with another component to integrate this information during a task depending upon the type of repressions and resources used by a task. Although Engle's approach is important with regards to the use of attentional control within a task, for the overall aim of the current thesis, it cannot be used to explain the change in representation use within quantitative change detection protocols across array sizes 4 and 6.

One final theoretical perspective, from Pearson (2001) suggests that another component could have been a use here; however, the prospect of this throughout the quantitative change detection task is unlikely. This component was named as the Visual Buffer and was suggested to be responsible for the consciously maintaining visual imagery in working memory. The Visual Buffer cannot be suggested as an explanation of these current thesis results as the Visual Buffer was primarily responsible for visual and spatial material only.

With there being no direct links from the Visual Buffer to the verbal material in the model, this again is a visual specific component and there would need to be another component, such as an episodic buffer as proposed by Logie (2011), to integrate the visual and verbal information whilst completing a visual memory task. The Visual Buffer, however, does require support from other working memory components such as a Central Executive which controls the allocation of material to each slave system component. The Central Executive would need to have the ability to store and hold both visual and verbal material at the same time, however it does not have the ability to do so, meaning the Central Executive can only be suggested as a control between the slave systems.

Similarly, Kosslyn's Computational model cannot be used to discuss the working memory architecture of the current quantitative change detection task. Kosslyn's model was suggested to use the Visual Buffer to store visual images within memory. Although this model used a Visual Buffer which could use recently perceived information or information which had been stored in long-term memory, Kosslyn did not indicate whether the use of long-term memory included both visual and verbal material. One of the main aims of Kosslyn's model was to suggest that visual images could be held in both short-term and long-term memory, using spatial and visual elements of the image. As the current doctoral thesis discussion is concerned with the use of verbal information, Kosslyn's model lacks clarification of whether verbal information could be used during the processing of visual images.

9.4 Qualitative Change Detection task – general or specific resource use?

Throughtout the development of the thesis, differences have been present between the smaller (5-10%) changes and larger (15-20%) changes in shape size. The first discussion points within this section, will relate to the large changes in the qualitative visual arrays only with the second section focussing upon the smaller changes in visual arrays.

As with the quantitative change detection task, the qualitative change detection task demonstrated effects of verbal interference within an adult context only. This was evidenced specifically in relation to the larger 15% and 20% changes in the qualitative visual arrays. These results were similarly presented within the ERP investigation whereby the qualitative task demonstrated a larger N400 amplitude, especially with the larger changes compared to the smaller changes.

The ERP and the dual task work suggest initially that this task may be domain general (or more multicomponent) in nature (Logie, 2011) as both the N200 and the N400 components demonstrated heightened activation during the qualitative task. However, finer analyses of the protocol, where the size of change was considered indicated that it was only in the larger change contexts where verbal interference occurred and in these contexts the N400 component was significantly larger than with the smaller changes.

Within the developmental investigation, only full scale IQ and non-verbal intelligence could be predicted but developmental fractionation trends were presented within the change detection protocols.

The results of study 6, using children aged 7-13 years indicates that the qualitative change detection task may primarily use visual representation which is a similar proposal to that of Hamilton (2013). Hamilton (2013) suggested that in a developmental context, the qualitative task requires a large amount of visualization of precise visual detail or appearance. There the high fidelity representation demand of the task is more likely to preclude any support from long term memory or verbal semantics. Within the adult context (from study 4), this visual specific nature was not the case due to the presence of visual and verbal interference effects.

Due to the nature of the representations appearing to be different within the large and small changes of the shape stimuli, two conclusions will be made regarding which model may be most appropriate to use.

Large Changes in Visual Arrays

The first discussion of models is related specifically to the large changes only of the qualitative change detection protocol. Even though the qualitative change detection task displayed slightly different representation use than the quantitative change detection task, Logie's working memory approach can still be considered most appropriate here for the large changes only due to the fact that the interference was not visual specific in the adult context (dual task and ERP investigations).

As with the quantitative change detection task explanations, neither Baddeley nor Cowan's models can be used to discuss the large changes of the qualitative change detection task. Baddeley's model is visual specific and clearly states that no verbal information is used during a visual task, as Luck and Vogel (2013) also suggested.

Cowan's model could not account for the differences in the percentage changes for the encoding arrays as this model is again associated with long term memory. The percentage change stimuli of the qualitative task had been created solely for the purpose of the thesis and participants had not had prior knowledge of the task. Again, the 500 millisecond encoding time was produced to be in line with the quantitative change detection task and to eliminate any potential effects of long term memory representations.

Baddeley's (2012) domain specific approach also could not account for the results of the qualitative change detection task. In Baddeley's model, the Central Executive component is the only component which could have been suggested to moderate the integration of visual and verbal information. As this component was suggested to only supervise the slave systems within memory, the Phonological Loop and VSSP, this Central Executive does not actually use the visual and verbal information itself. The information is directed into memory through each separate working memory component on a perceptual level, meaning that the visual information stays within the VSSP. The Central Executive acts as a way of allowing information to move in and out of the slave systems, however the visual and verbal information are kept distinctly different from each other. The possible use of a Central Executive would require further investigations using the quantitative and qualitative change detection tasks. As Brown and Wesley (2013) was a key piece of research used for the thesis, their executive interference task could be used in a similar dual task paradigm of chapters 5 and 6 of the thesis. The potential binding of shape and size within the qualitative change detection task could also have an impact upon how the executive interference affects results. Baddeley (2000) suggested that the Central Executive could be responsible for processes such as binding, therefore any interference effects of the qualitative change detection task (using binding encoding arrays) could give researchers a further implication of the use of the Central Executive component within memory.

Similarly, to the quantitative change detection task, Pearson's approach also cannot be seen to explain the results of the large changes within the qualitative change detection protocols. Pearson's (2001) Visual Buffer was suggested to provide links between the visual and spatial working memory components; however, links were not presented between the visual and verbal components within the model, except through the Central Executive component. As this component was not designed to integrate visual and verbal information, another component would need to assist the visual buffer to allow the use of both visual and verbal material within the working memory architecture.

As with the quantitative change detection task, the large changes within the qualitative change detection task cannot be explained by Kosslyn's Computational model as this model was concerned with the storage and processing of visual and spatial information. As the links between the Visual Buffer and long-term memory did not include any explanations of verbal information use, this model cannot be used as a suitable explanation of the working memory architecture of a qualitative change detection task.

Small Changes in Visual Arrays

Although the larger changes in the qualitative visual arrays may appear to use visual and verbal information types, the small changes in the qualitative visual arrays do not. The smaller changes were shown to display any interference effects and the amplitude of the N400 was lower within the small changes, indicating a lower use of semantics within such changes.

From this, it can be suggested that the model of Logie (2011) cannot be used to explain the results of the smaller shape changes. As there was no presence of any verbal interference effects and the N400 ERP amplitudes were reduced for the smaller changes, there is a lack of evidence for the use of verbal semantics when participants were faced with smaller changes. This means that the use of an Episodic Buffer component was not necessary as there were no elements of verbal information to support the visual representation use.

The visual specific models, on the other hand, such as those proposed by Baddeley (2012) and also the use of a Visual Buffer, as suggested by Kosslyn (2006) and Pearson (2001) could be used as an explanation for current results. Baddeley (2012) proposed that visual working memory tasks to be visual domain specific due to the way in which the information is directed through the model. Baddeley's gateway approach could account for the visual domain specific nature of the smaller changes in the qualitative task. As the information about small changes may be directed through a model on a more perceptual level, with no influence of semantics, and straight into a component such as the VSSP, this could explain how the smaller changes in visual arrays were not susceptible to any form of verbal semantics. The use of a Central Executive component within this model could suggest how information is directed through the model, whereby visual and verbal types of material are not integrated. This could also be the case within a developmental (as well as an adult) context as the results of study 6 indicated that the qualitative change detection protocol could only predict the non-verbal intelligence and also the full scale IQ score.

Pearson (2001) had discussed the Visual Buffer component in terms of being able to link the Inner Scribe and the Visual Cache components within memory. Within this model, Long Term Memory may still be at use, however this type of Long Term Memory is seen as visual in nature and the types of representations are seen as visual, with no implications of semantic or verbal representation use. The Visual Buffer may well be a possible explanation for the functional working memory architecture of the smaller qualitative changes. Pearson (2001) noted that the Visual Buffer was able to work with the Visual Cache and Inner Scribe to only pass small chunks of information (at a time) through memory. With the small, high fidelity representations used during a qualitative change detection protocol, these representations may need to be passed through a model several times before being completely stored in memory and the bi-directional nature of Pearson's approach would allow this to happen.

In Chapter 1 of the thesis, details were given with regards to the working memory model proposed by Engle et al. (1999). This model focuses upon the importance of the Central Executive and how this component uses attentional control to pass representations through the model. In a similar way to Cowan et al. (2005), the model from Engle et al (1999) cannot be used to explain the results of the current doctoral thesis in relation to any of the investigated contexts, including the differences between the small and large changes in shape size. Although the model from Engle et al. (1999) gave important details regarding the use of attentional control and how this can influence memory storage, no reference was made to the different types of information used by different working memory tasks. As Engle et al. (1999) highlighted the importance of the Central Executive's attentional control abilities, this can only give suggestions of how information can be used by both Long Term Memory and Short

Term Memory, and not details of the types of information this is. Engle's approach did not distinguish between the use of visual and verbal information and suggested that all types of information were directed through the model in a similar pattern. This also indicates that the differences between smaller and larger changes in shape stimuli could not be accounted for and this approach can also not be used with regards to the qualitative change detection protocol. It could be suggested that two separate components may be needed for the maintenance of visual and verbal representations and Logie's working memory model has two separate components for these representation types, with the Episodic Buffer as a way of controlling the use of the visual and verbal representations within a task.

The next section will now conider methodological implication and the directions for future research in light of the current thesis results.

9.5 Methodological Considerations and Future Research

The current quantitative and qualitative change detection tasks have both been used in different contexts (adult behavioural, ERP and developmental) to provide converging evidence that they are appropriate to use in the measurement of purely visual working memory capacity. Each task was created for the purposes of the current thesis and there were strengths in doing so.

The quantitative change detection task has successfully been used in both adult (Luck and Vogel, 1997) and also developmental contexts (Riggs et al., 2006) to show how visual working memory capacity can be measured and evidence from the child participants demonstrated the developmental fractionation of these change detection tasks. The current research has suggested that this task can also be used within an electrophysiological context to show how the brain processes visually presented arrays. The use of these two change detection procedures in the same situations has provided a comparison of the tasks which has never been seen within the literature before. Only Fukuda et al. (2010) used a quantitative and qualitative visual change detection task within the same investigation, however these tasks were very similar and it could be suggested that confusion could have occurred between the tasks if their participants misunderstood the differences between the quantitative and qualitative visual arrays. The current thesis, however, used two completely different working memory capacity tasks to assess the qualitative and quantitative measures visual working memory capacity. By doing this it ensured that participants clearly knew that there were two types of tasks and that there were no confusions between task instructions.

Another strength regarding the change detection methodologies was the use of the 500 millisecond encoding time. Previous researchers such as Orme (2009) and also Lin and Luck (2008, 2012) suggested that there could be differences with regards to longer and shorter encoding times in visual working memory tasks, such as the use of long term memory. The current research aimed to reduce the effect of long term memory by using the 500 millisecond encoding time originally suggested by Luck and Vogel (1997). Luck and Vogel's 100 millisecond encoding interval may have been unsuitable to use in this research, in particular with a developmental context and interference contexts as the change detection tasks needed to ensure that all information was fully encoded into memory. Orme (2009) suggested that each item in memory only needs 50 milliseconds to allow for encoding to occur, therefore the 100 millisecond interval would have been too short with the array sizes above two squares. The 500 millisecond interval allowed enough time for encoding to occur without the use of long term memory repressions.

There were several limitations to the current research which enable direction for future research. Although the current research has demonstrated the use of verbal and visual representations within an adult context, suggestions were made briefly regarding the potential use of the Central Executive resources such as the Episodic Buffer (Baddeley, 2012). An alternative to the Episodic Buffer as suggested by Logie (2012) could potentially be the Central Executive component which controls to information directed to the visual and phonological stores. To investigate whether the Central Executive was a key component within the quantitative and qualitative change detection tasks, further studies would need to be conducted to investigate this section of the working memory architecture. Brown and Wesley (2013) had used random tapping as the executive interference measure. A similar task could be used within the current context to look at the use of the Central Executive. This could give a clearer idea of whether Logie's working memory model of Baddeley's Multi-Component model is the most appropriate to use for the explanation of the change detection tasks.

Another limitation was the potential use of binding present within the qualitative change detection task. The binding of shape and colour was a suggestion made in both the qualitative interference study (experiment 4, chapter 6) and also the ERP investigation (experiment 5, Chapter 7) as an explanation for results. The current thesis used the paradigm rom Bae and Flombaum (2013) and used the two different shapes as suggested to reduce any form of correspondence errors. However, the binding processes themselves could not be inhibited as the task involved the encoding of colours, shapes and sizes even though the participant had to recall size only. To recall the size of an object, the participant had to store the shape, size and colour of the initial encoding objects. This concept of binding accounting for results could be investigated further by using the bindings as suggested by Wheeler and Treisman (2002), Luria and Vogel (2011) and Baddeley, Allen and Hitch (2011). The quantitative and qualitative change detection tasks had not been considered in this way prior to the creation of the encoding arrays. A series of studies could be developed using the qualitative change detection task to investigate further whether any binding effects were present within the data.

This would mean creating a new full set of stimuli which had potentially different biding conditions (colour and shape, size and shape) to see if the current results were affected by this.

One other consideration with regards to the creation of the qualitative change detection protocols used in the current thesis could look at the ratio of small (5-10%) and large (15-20%) changes in the qualitative shape arrays. Within the qualitative dual task investigations, it was found that the verbal interference was only targeting the larger changes in the visual arrays, initially suggesting that the smaller changes may not be susceptible to interference. This was a similar case with the increased N400 amplitude with the larger 15% and 20% changes in relation to frontal lobe activity, indicating the presence of long term memory and semantic information use. The use of smaller changes, and not larger changes in the visual arrays could make the qualitative change detection protocol more qualitative and also more visual apecific in nature. The larger 15% and 20% changes in the visual arrays may be seen as more quantitative arrays, leading participants to store these representations using visual and verbal types of information. The smaller changes, however, have demonstrated the ability to store high fidelity types of representations using primarily visual information and these types of representations may not be supported by the use of verbal semantics, similar to suggestions made from Hamilton (2013) when discussing a qualitative Size JND task.

Alternative qualitative tasks from Heyes et al. (2012) and also Zhang and Luck (2008) have used tasks which have measured precision using a recall task and not a recognition task such as the change detection tasks being used in the current thesis. It could be the possibility that these measures can be seen as pure measures of qualitative stimuli as these tasks encourage the storage of very high fidelity representations, for example, the colours from a colour wheel or the location from a bar rotation task. Although the current thesis did use small-change stimuli which promotes the use of such high fidelity representations, using a colour wheel experiment in comparison to a change detection measure would provide researchers with further details about the functional working memory architecture of such visual memory tasks to discover if the type of task (recall or recognition) plays a role in the multicomponent and/or domain specific nature of visual working memory tasks.

One final limitation to note could be the sample within the qualitative interference paradigm as these were all female. Within the other 5 thesis studies, a sample of both males and females were used, however during the qualitative interference procedure, only females were recruited. Gender differences have been apparent within other visual working memory contexts (Della Sala et al., 1997) therefore these may apply to the current qualitative change detection task. In future, a sample of males and females would enable the results to be more generalizable to males and females.

9.6 Conclusions

The results from this thesis have provided evidence towards two particular theoretical perspectives regarding the use of visual and verbal information in a quantitative and a qualitative change detection task, specifically within an adult context. The multicomponent approach to the working memory architecture, as proposed by Logie (2011), is suggested to allow the integration of visual and verbal information during a visual working memory task, primarily focussing upon the quantitative change detection task and also the larger changes within the qualitative change detection task. This theoretical perspective was presented in the discussion section and contrasting models of working memory were also considered such as those of Baddeley (2012), Pearson (2001) and Cowan (2005).

Focussing upon a quantitative change detection task, it can be concluded that Logie' working memory model can be used to best discuss the links between the visual and verbal information use during this task, however primarily within the adult context as the attentional allocation processes may not be fully developed in a developmental sample. Visual information and potentially visual resources are initially recruited to assist with the memory of the coloured material. Once the visual resources have been used, verbal information and resources are then recruited to support storage when the visual resources have reached maximum capacity. Logie (2011) suggested that an Episodic Buffer component could be used to manage the integration of visual and verbal material, and it appears that the current thesis has also suggested that this could be the case. In an adult behavioural and electrophysiological study, the use of visual and verbal information has been shown to be present, however the lack of predictions of intelligence in the developmental context lead researchers to believe that the multicomponent nature of this task may be specific to adults. Where the larger array sizes were apparent, it was clear that the resources used were simply those that were available at the time of task completion in the adult samples. With regards to the lack of links within the developmental context, although the capacity limit of 3-4 items can be fully developed at this age, the working memory processes involved relating to the Episodic Buffer (attentional control mechanisms) could still be developing, giving the indication of a lack of clear resource use here. Models such as Kosslyn's Computational Model and Pearson's approach were perspectives that were also considered. However, as there is no clear link between any verbal and visual information use within these approaches, the models cannot be used as a discussion of the functional architecture of a quantitative change detection task.

When focussing upon the qualitative change detection tasks, conclusions were tailored to the separation of the smaller and larger changes in shape stimuli as this is one aspect that needs to be considered during the creation of a qualitative change detection protocol. The utilisation of domain general resources and semantics was dependent upon the nature of the fidelity of the representation (domain general or multicomponent in nature for the large changes). Accuracy in the small change context, where high fidelity resolution maintenance of the stimulus was required, revealed less behavioural and electrophysiological characteristics associated with verbal semantic recruitment and this indicated a more visual specific approach in relation to the smaller changes. Within the developmental context, the links between the qualitative measure and non-verbal intelligence can leave us with suggestions that children may primary focus upon using visual resources within memory. Alongside considering the model of Logie (2011) for the larger changes in visual arrays, the model from Baddeley (2012) and also Pearson (2001) can be considered for the visual domain specific nature of the task in relation to the smaller changes to visual arrays, also evidenced within a developmental context. The potential use of a Central Executive could give indications of how the smaller changes may be seen as visual specific, when information is directed through the model on a perceptual and non-semantic level and the bi-directional nature of Perrson's approach would mean that memory representations could be directed through the model several times until such high fidelity details were remembered.

A consideration was made to Cowan's Embedded Processes model with this task, however it can be concluded that the results of this thesis cannot be attributed to Cowan (2005). Cowan (2005) suggested a link between activated long term memory and the short-term storage within memory. As the current change detection tasks aimed to reduce the effects of long term memory by using a 500 millisecond encoding duration, there appears to be no other explanation as to why verbal resources were recruited in instances when visual information was not available.

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APPENDICES

Appendix A

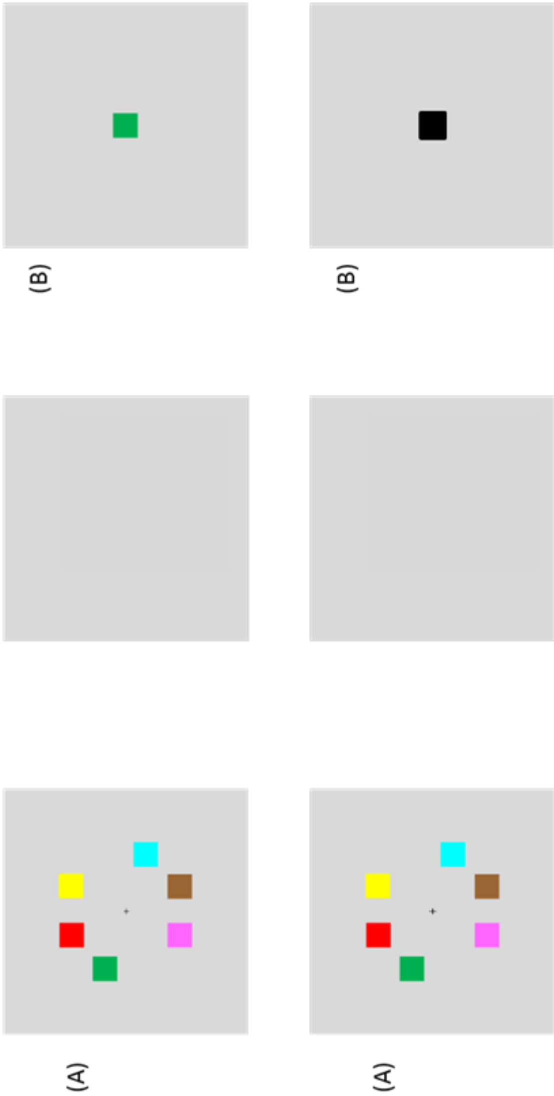
Participant Instructions for the Quantitative Change Detection Task

Quantitative Change Detection Task – studies 1, 2, 5

This task is a square visual memory task. You have to decide if the single square shown in the second picture (B) is the same colour as any one presented in the first picture (A).

An example of the colour being the same.

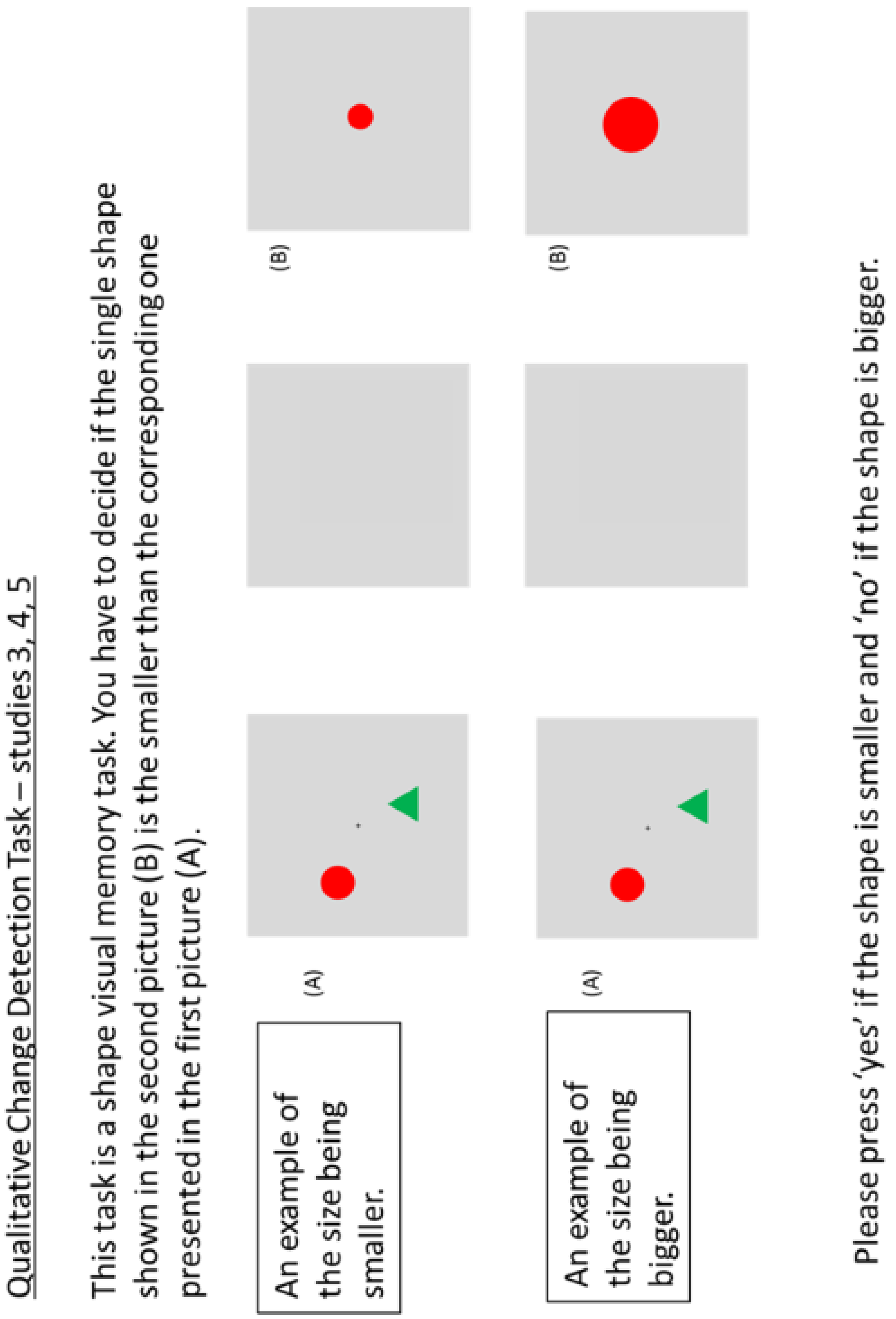
An example of the colour being different.



Please press ‘yes’ if the square is the same colour and ‘no’ if the square is a different colour.

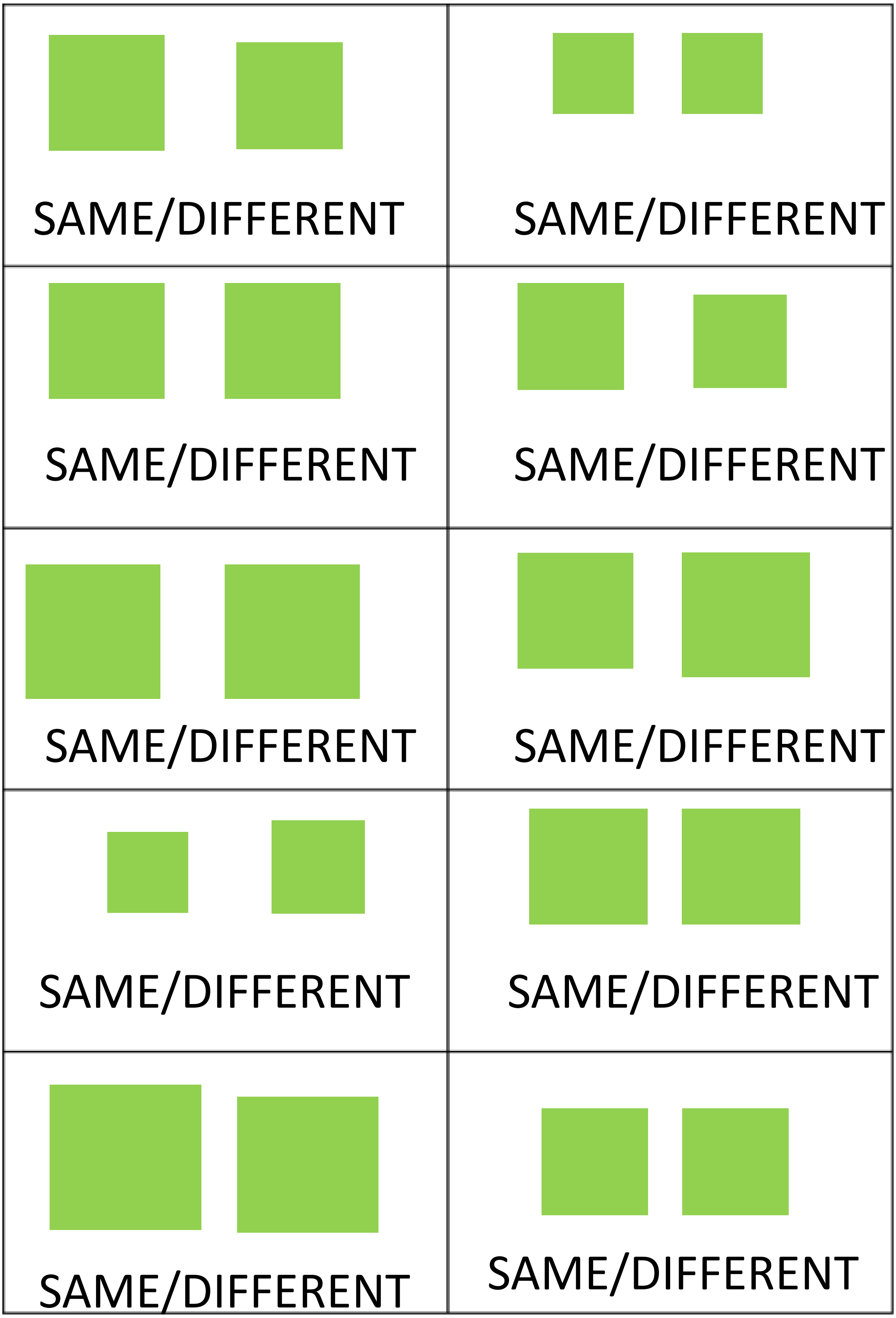
Appendix B

Participant Instructions for the Qualitative Change Detection Task



Appendix C

Paper Based Perceptual Task for Study 3



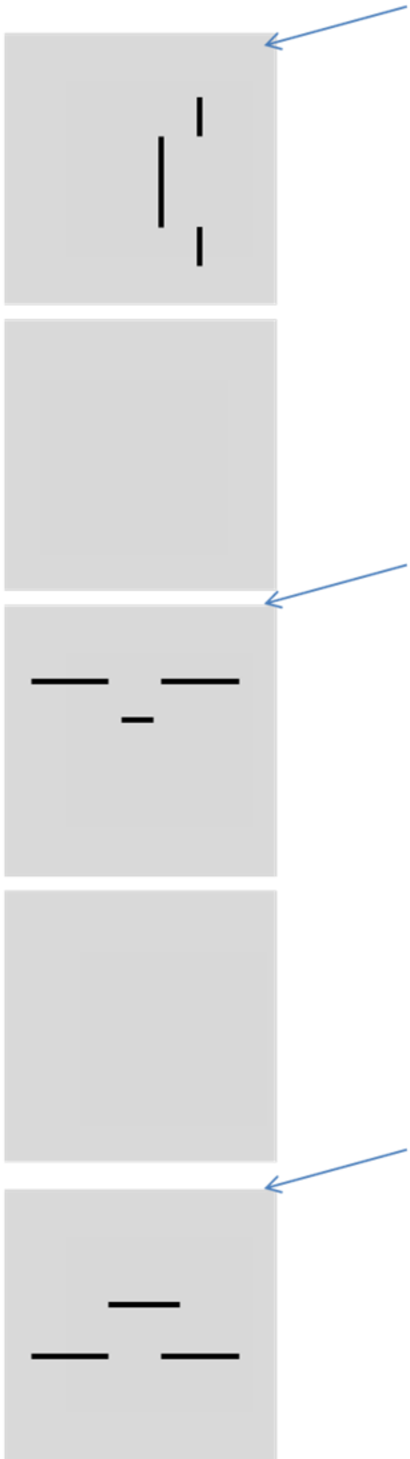
Appendix D

Participant Instructions for the Bar Fit Task

Visuospatial Attention Instructions – studies 2, 4

This task is called the Bar Fit Task.

The aim of this task is to decide if the middle bar can fit between the gap in the two other bars



Respond yes/no

Respond yes/no

Respond yes/no

After each individual picture has been shown, press 'yes' if the bar does fit or 'no' if the bar does not fit.

Please DO NOT wait until the sequence of three images has finished otherwise your responses will not be recorded correctly.

Appendix E

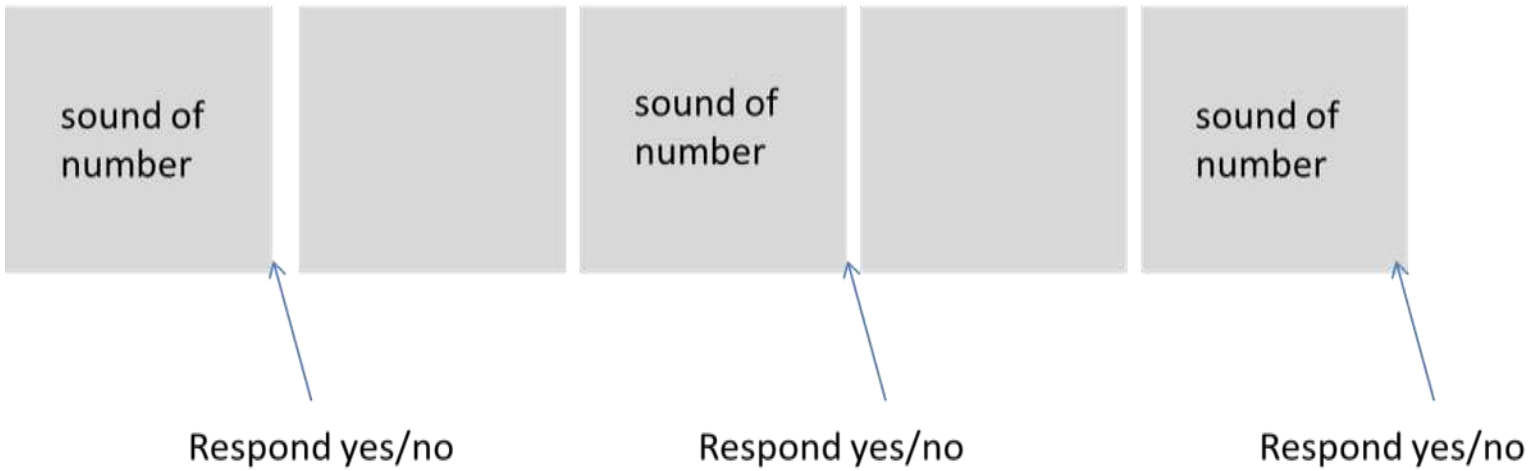
Participant Instructions for the Verbal Parity Task

<u>Verbal Attention Instructions – studies 2, 4</u>

This task is called the Number Naming Parity Task.

For this task, you will hear three numbers being spoken through headphones.

The aim of this task is to decide if each spoken number is even or odd.



<u>**After each individual**</u> number has been spoken, press ‘yes’ if the number is even and ‘no’ if the number is odd.

Please DO NOT wait until the sequence of three images has finished otherwise your responses will not be recorded correctly.

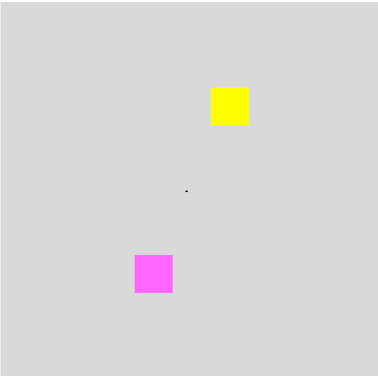
Appendix F

Examples of Participant Instructions for the Developmental Change Detection Tasks

Faculty of Health & Life Sciences

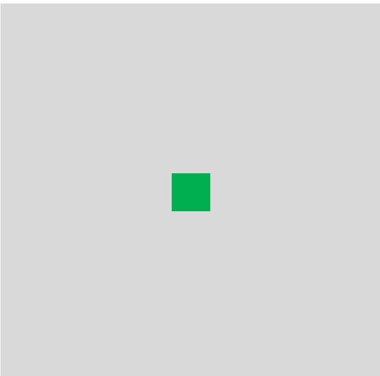
Child Information Sheet

Quantitative Task



You will be shown a picture of two squares.

You will then be shown a blank screen.



You will then be shown a second picture of one square.

Is the one square in the second picture the same colour as any square in the first picture?

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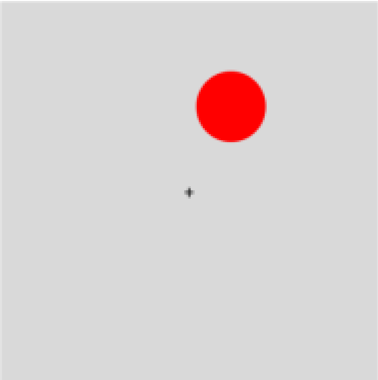
Faculty of Health & Life Sciences

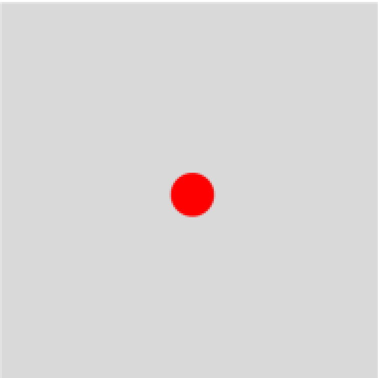
Child Information Sheet

Qualitative Task



You will be shown a picture of one shape.

You will then be shown a blank screen.



You will then be shown a second picture of one shape.

Is the one shape in the second picture bigger or smaller than in the first picture?

Appendix G

Example Task Order for the Dual Task Procedures

In study 2 (quantitative interference) the numbers 1 and 2 were replaced by the numbers 4 and 6 to represent the different array sizes.

P 1	1_2_Mem _Perc	1_2_Mem _Prac	1_Mem_B ase	VS_Int_Pe rc	VS_Int_Pr ac	VS_Int_B ase	Verb_Int_ Perc	Verb_Int_ Prac
P 1	Verb_Int_ Base	1 memory + VS Int	1 memory +Verb Int	2_Mem_B ase	2 memory + VS Int	2 memory +Verb Int		
P 2	Verb_Int_ Perc	Verb_Int_ Prac	Verb_Int_ Base	VS_Int_Pe rc	VS_Int_Pr ac	VS_Int_B ase	1_2_Mem _Perc	1_2_Mem _Prac
P 2	1_Mem_B ase	1 memory +Verb Int	1 memory + VS Int	2_Mem_B ase	2 memory + VS Int	2 memory +Verb Int		
P 3	1_2_Mem _Perc	1_2_Mem _Prac	1_Mem_B ase	Verb_Int_ Perc	Verb_Int_ Prac	Verb_Int_ Base	VS_Int_Pe rc	VS_Int_Pr ac
P 3	VS_Int_Ba se	1 memory + VS Int	1 memory +Verb Int	2_Mem_B ase	2 memory + VS Int	2 memory +Verb Int		
P 4	Verb_Int_ Perc	Verb_Int_ Prac	Verb_Int_ Base	1_2_Mem _Perc	1_2_Mem _Prac	2_Mem_B ase	VS_Int_Pe rc	VS_Int_Pr ac
P 4	VS_Int_Ba se	2 memory +Verb Int	2 memory + VS Int	1_Mem_B ase	1 memory +Verb Int	1 memory + VS Int		
P 5	Verb_Int_ Perc	Verb_Int_ Prac	Verb_Int_ Base	VS_Int_Pe rc	VS_Int_Pr ac	VS_Int_B ase	1_2_Mem _Perc	1_2_Mem _Prac
P 5	1_Mem_B ase	1 memory + VS Int	1 memory +Verb Int	2_Mem_B ase	2 memory + VS Int	2 memory +Verb Int		

Key For Appendix G

In study 2 (quantitative interference) the numbers 1 and 2 were replaced by the numbers 4 and 6 to represent the different array sizes.

VS_Int_Perc = Paper example of bar fit task

Verb_Int_Perc = Paper example of verbal parity task

1_2_Mem_Perc = Paper example of primary task

VS_Int_Prac = Practice of bar fit task

Verb_Int_Prac = Practice of verbal parity task

1_2_Mem_Prac = Practice of primary task

VS_Int_Base = Baseline task of bar fit task

Verb_Int_Base = Baseline task of verbal party task

1_Mem_Base = Baseline task of primary task array size 1

2_Mem_Base = Baseline task of primary task array size 1

1 memory + VS Int = Dual task: array size 1 primary plus bar fit task

1 memory +Verb Int = Dual task: array size 1 primary plus verbal parity

2 memory + VS Int = Dual task: array size 2 primary plus bar fit task

2 memory +Verb Int = Dual task: array size 2 primary plus verbal parity

Appendix H

Calculation of K Scores

Choosing Cowan et al. (2005) for the calculation of the K-Scores was shown to be the most appropriate as Cowan's work included statistics for both multiple and single retrieval probes. The current results had initially been analysed using a full retrieval probe calculation from Shipstead et al. (2014) and an issue arose, with the presentation of negative K scores. Shipstead's full probe formula was shown as k = N* (hits – false alarms/(1 – false alarms) which was originally the whole display correction from Pashler (1988). Negative K scores produced could have suggested that participants may have misunderstood the task instructions and reversed the keyboard keys. In the current study, however, this was shown to not be the case as the scores for array sizes 1 and 2 suggest a high accuracy in performance and it indicates that participants did fully understand the task.

Cowan et al. (2005) had noted issues with the full probe formula from Pashler (1988) due to a misplaced bracket when the formula was created. Cowan et al. (2005) therefore created a new full probe K calculation as well as the single probe correction. Please see the two calculations from Cowan et al. (2005), below.

Cowan et al. (2005) Full Probe K Calculation

k = N*(H+CR-1)/CR

Cowan et al. (2005) Single Probe K Calculation

(***k = N*(H+CR-1)***

<u>Where:</u>

N = array size displayed, H = hit rate = the amount of correct detections.

CR = correct rejection rate = the amount of correct responses that are rejected (e.g. amount of non-changes detected)