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Queen Margaret University
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THE CONTRIBUTION OF THE CENTRAL EXECUTIVE TO VISUO-SPATIAL BOOTSTRAPPING IN YOUGER ADULTS, OLDER ADULTS AND PATIENTS WITH MILD COGNITIVE IMPAIRMENT

CLARA CALIA

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Abstract

Background. Recent studies on verbal immediate serial recall (Darling & Havelka, 2010; Darling et al., 2012, 2014; Allen et al., 2015) show evidence of the integration of information from verbal and visuo-spatial short term memory with long-term memory representations. This so-called ‘visuo-spatial bootstrapping’ (VSB) pattern, in which verbal serial recall is improved when the information is arranged in a familiar spatially distributed pattern, such as a telephone keypad, is consistent with the existence within working memory of an episodic buffer.

Objective. The general purpose was to investigate the structure of working memory, and in particular the relationship between verbal and visuo-spatial working memory. Specifically, this thesis aimed to determine the contribution of the central executive and the implications of the VSB paradigm in younger and older adults and patients with Mild Cognitive Impairment (MCI).

Materials and Methods. The first study explored the role of the central executive. The VSB task with digit sequences, visually presented both in single and in a typical keypad display, was administered under conditions of verbal and central executive load. In the second study VSB was investigated in older and younger adults using three conditions: single digit display, typical and random keypad. In the third study, examining performance in VSB in a typical elderly sample compared with people with MCI. Each participant was assessed with a neuropsychological battery of tests and the VSB task composed by single digit and typical keypad display.

Results and Conclusion.
Central executive load demonstrated to have a negative effect on digit recall performance without affecting the bootstrapping effect. VSB does not need to recruit executive resources. No difference was observed in the bootstrapping pattern as a consequence of age and cognitive difficulties and the beneficial impact of additional visual information was comparable for MCI, older and younger participants.

Keywords: Working memory, binding, episodic buffer, visuospatial bootstrapping, central executive, younger adults, aging, mild cognitive impairment

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INTRODUCTION

Working memory (WM) refers to the cognitive mechanisms supporting moment-to-moment storage and updating of information. Working memory is invoked whenever information has to be retained over short periods, such as when remembering a telephone number, but also when information has to be processed on a moment-to moment basis, such as when performing mental arithmetic (Baddeley, 2007).

Current models of working memory (e.g. Baddeley, 2000; Cowan, 2001, 2005; Logie, 1995, 2003; Engle, Kane, & Tuholski, 1999) encompass a broad array of processing and storage functions and propose that working memory itself functions as an ensemble of different processes. According to the multi modal working memory model (Baddeley & Hitch, 1974), at the basic level there are so-called ‘subsystems’, broadly passive stores that maintain information over short periods. Sub systems are thought to be somewhat distinct from each other; for example, phonological information is retained in a separate system, the phonological loop, to visuospatial information. Other processes can manipulate information while it resides within these stores. The majority of such processes are considered part of a central executive (CE), a limited set of control resources that are recruited for tasks such as planning, sequencing and inhibition. In this model, a crucial role is provided by the episodic buffer which is a temporary storage system that combines information from the two sub system and long-term memory in a meaningful representation. In a different way, other researchers have questioned the assumption that short-term memory and long-term memory are separate cognitive systems (Postman, 1975; Neath, Brown, Poirer & Fortin, 2005; Ranganath & Blumenfeld, 2005), supporting the unitary view of memory. The most influential model which supports the unitary view is the embedded process model by Cowan (1988; 1995; 1999; 2005) which consists of a brief sensory store, long-term memory, activated long-term memory and central executive. Another relevant different model of working memory has been proposed by Logie (1995, 2003) who describes working memory as a mental workspace which maintains and manipulates online data. In this model, working memory is considered as an independent mental workspace which is activated by long-term memory and it is involved in maintaining and manipulating information, both verbal and visuo-spatial.

There is good evidence supporting the segregation of verbal and visuo-spatial temporary memory systems (e.g. Smith, Jonides & Koeppe, 1996; Baddeley, Lewis & Vallar, 1984; Quinn & McConnell, 1996). However, situations arise where a stimulus has attributes that fall into both domains: tasks where participants must remember the location and content of a verbal stimulus require not only encoding in both subsystems, but also a way of linking them together. In order to account for this (among other issues), Baddeley (2000) proposed a further component of working memory, the episodic buffer (EB). This limited capacity store is assumed to be recruited when information from different sources, including the working memory subsystems and long-term memory (LTM), has to be bound together and temporarily retained, for example, remembering what item went where, or remembering that a word was presented in red ink. Evidence indicates that 'bound' representations of such stimuli are indeed formed in memory (e.g. Allen, Baddeley, & Hitch, 2006; Allen, Hitch, & Baddeley, 2009; Baddeley, Hitch, & Allen, 2009; Bao, Li & Zhang, 2007; Karlsen, Allen, Baddeley, & Hitch, 2010).

Although laboratory binding tasks are somewhat artificial, there is recent evidence of interaction between verbal and visuo-spatial working memory in a more ecologically valid digit span task that does not explicitly ask participants to 'bind' information (Darling & Havelka, 2010; Darling, Allen, Havelka, Campbell, & Rattray, 2012; Darling, Parker, Goodall, Havelka, & Allen, 2014; Allen, Havelka, Falcon, Evans, & Darling, 2015). This effect was termed 'visuo-spatial bootstrapping' (VSB). Participants were shown sequences of digits for immediate recall. When these were presented by 'lighting up' a sequence of digits in a spatial array that was arranged as a traditional telephone keypad, digits were better remembered than if they were presented as single digits in the centre of the screen. This was assumed to reflect the fact that visuo-spatial information, either in working memory or long-term memory, was bound to verbal digit information which facilitates performance.

Research question

This research topic originates from recent studies on visuo-spatial bootstrapping (VSB; Darling & Havelka, 2010; Darling et al., 2012, 2014; Allen et al., 2015) as an effect that shows how visuo-spatial information can be used to support verbal memory. Visuo-spatial bootstrapping involves the integration of information from verbal and visuo-spatial short -term memory (STM) with long-term memory (LTM) representations. Evidence of the existence of bootstrapping effect in working memory therefore supports the model which includes the episodic buffer (EB; Baddeley, 2000; Baddeley, Allen, & Hitch, 2011), which is a limited temporary storage system where information from different sources is integrated and temporarily retained (Baddeley, 2000).

The aim of the research presented in this thesis was to carry out a series of three studies to investigate visuo-spatial bootstrapping through the examination of the contribution of subcomponents of working memory in visuo-spatial bootstrapping across the lifespan and in a sample of person who started to show memory impairments. Specifically, this thesis aimed to determine the contribution of the central executive and the implication in younger and older adults and patients with mild cognitive impairment of visuo-spatial bootstrapping paradigm (Darling & Havelka, 2010; Darling et al., 2012, 2014; Allen et al., 2015).

Literature Review

CHAPTER 1

1.1. Working memory (WM)

1.1.1 Introduction

The expression Working Memory was coined for the first time by Miller, Galanter and Pribram (1960) and used later by Atkinson and Shiffrin (1969). As will be explained later, this term now often refers to the multi component model by Baddeley and Hitch (1974).
Working memory (WM) refers to the cognitive mechanisms which maintain process, store and update information for the execution of multiple complex tasks, such as understanding, learning and reasoning. It also allows the integration of information from the sensory systems and long-term memory (semantic memory, episodic, autobiographical) (Baddeley et al., 2009). In fact, working memory plays a key role in complex cognition, like the cognitive tasks that we carry out daily (eg reading a newspaper, comparing the various prices of a particular product to determine which is the cheapest) and in a broad range of tasks beyond simple memory tasks, including activity such as planning, learning a language (Baddeley, Emslie, Kolodny, & Duncan, 1998) and navigation of the environment (Garden, Cornoldi, & Logie, 2002). As it can be expected, working memory is relevant for several important tasks such as arithmetic (Just & Carpenter, 1992) and comprehension (Gathercole, Pickering, Knight, & Stegmann, 2003). These tasks usually require multiple steps with intermediate results that must be kept temporarily in mind to successfully perform the task that is being carried out (Miyake & Shah, 1999). Working memory is used to define the ability to hold in mind and manipulate information mentally in a limited period of time and it handles everyday activities such as following spoken directions and recalling the unfamiliar foreign name of a person. According to this description of working memory, it can be argued that it could be considered as a single factor influencing general intelligence (Süβ, Oberauer, Wittmann, Wilhelm, & Schulze, 2002), which has in fact been correlated with working

memory capacity (Conway, Kane, & Engle, 2003). It has been observed that working memory capacity seems to increase with age. Young children typically have limited capacity that raises gradually until adolescence and then gradually declines until older age (Gathercole et al., 2003).

Working memory is limited and can easily fail in specific situations where there is distraction (Logie, Zucco & Baddeley, 1990) (it can be an unrelated thought or an interruption such as a phone call that can be sufficient to divert attention), or when holding in mind too much information or performing demanding tasks, such as activities that require difficult mental processing.

1.1.2 Working memory and Short-term memory

The difference between the two different descriptions of memory, “short-term memory” (STM) and “working memory” (WM), has often created confusion in the literature.
In the past, the concept of short-term memory has been used in various ways by different authors (James, 1890; Broadbent, 1958; Atkinson & Shiffrin,1968). It can be defined as the “faculties of the human mind that can hold a limited amount of information in a very accessible state temporarily” (Cowan, 2008, pp. 323-338). Short-term memory is known to be a system with limited capacity, which may be retained in a restricted amount of information for a short period of time. The units (individual elements or groupings still remembered as units) that can be held in this kind of memory system was initially considered to be about seven, two more or less, as measured in a famous work of Miller (1956). The information is subject to rapid decay, if there is not a process of repetition. Since the 1960s some authors (Atkinson & Shiffrin 1968; Hunter 1957; Newell & Simon, 1972) supported the idea that the short-term memory would play an important role in cognitive activities by acting as a temporary working memory in which the information was maintained and manipulated.
The construct of working memory was initially proposed by Baddeley (1986; Baddeley & Hitch, 1974; Baddeley & Logie, 1999) and was partly to replace short-term memory. Greater emphasis was placed on the active manipulation of information rather than on maintaining passive information as in short-term memory. Working memory, in fact,

while still incorporating short-term (capacity limited and temporary maintenance of information), was thought as a more complex system, as it simply did not work as temporary storage, but allowed to process information during the execution of several cognitive tasks. Baddeley and Hitch (1974) define working memory as the set of cognitive components that enable individuals to understand and mentally represent their surroundings, to keep information about their recent experiences, to support the acquisition of new knowledge, to solve problems and to formulate, connect and achieve specific goals (Baddeley & Logie, 1999). The main difference between them is that in working memory information is actively manipulated while short-term memory provides passive storage.

1.1.3 Working memory capacity

Several mechanisms play a relevant role retaining information. For this reason it has been difficult to determine the working memory capacity (Cowan, 2010). The ability in working memory can be measured through processing-related or storage-specific, in relation to the tasks used (Cowan, 2010).

The well-known paper "The magical number seven" by Miller (1956) defined seven the capacity limit for single digits and letters. More recently, Cowan (2001) has indicated that for passive storage four is the most likely amount of items to be recalled when the rehearsal is blocked in short-term memory. According to Cowan (2001), short-term memory and working memory present differences in relation to involvement of attention and rehearsal. Cowan (2010) claimed that three to five chunks is the limit of the central component of working memory in young adults. However, working memory capacity varies considerably among individuals and across the life span and it can infer intellectual ability and individual differences (Cowan, 2005). Training on working memory capacity seems to have an impact on increasing the number of items that can be remembered with computer tasks (Klingberg, Forssberg, & Westerberg, 2002), although evidence in this regard is unclear. According to Cowan (2010), tests that measure working memory have several limits depending on which processes are allowed to be used, such as rehearsal and grouping.

Two of the most widely used neuropsychological tests to assess short-term memory are the forward and backward digit span (Richardson, 2007), which are included in the

Wechsler memory scales (WMS; Wechsler, 1997, 1997a). In these tests the span is measured recalling digit sequences for forward and backward, with a reverse order of digits in the latter. The sequences of digits are initially presented with two digits with an increasing list length with two trials in each list. Testing procedure is stopped when subjects failed to recall both sequences in order. Span is determined to be the maximum sequence length at which participants recalled at least one sequence correctly (Woods, Kishiyama, Yund, Herron, Edwards, Poliva, Hink, & Reed, 2012).
Other tools have been developed to assess working memory capacity such as the family of complex span tasks (Daneman & Carpenter, 1980; Conway, Kane, Bunting, Hambrick, Wilhelm, & Engle, 2005). In these tests, subjects are required to solve a series of tasks following which they need to recall the final items of the task in correct serial order. The first complex span test was proposed by Daneman and Carpenter (1980), asking participants to read several sentences whereas they need to maintain the last word of each phrase. The span is determined by the total number of words recalled. Complex span tasks involve both short-term storage and concurrent processing, which are essential elements to consider in working memory assessment (Gagnon & Belleville, 2011). Moreover, what makes complex span task a valid and reliable tool of working memory functions is the control component (Engle & Kane, 2004; Jarrold & Towse, 2006). This test also correlates with a range of complex cognitive activities, such as general fluid intelligence (Engle, 2001), abstract reasoning (Engle, Tuholski, Laughlin, & Conway, 1999) and language comprehension (Daneman & Merikle, 1996). These correlations describe the main differences with the traditional span tasks, such as digit span (Daneman & Carpenter, 1980; Gagnon & Belleville, 2011).

One of the most studied characteristic of working memory is the individual differences in its capacity “span”. Investigations on working memory span showed that it can predict a broad range of complex cognitive tasks more efficiently than word span and episodic long-term memory, using tasks which required short-term stores and manipulation of information with complex working memory span measures (Baddeley, 2007).
There is a general consensus on individual and age-related variations in relation to the capacity of information that can be processed and maintained. However, several factors have been examined with a focus on different aspects. Some studies have as a target the quantity of activated and accessible resources (Engle, Cantor, & Carullo, 1992; Just & Carpenter, 1992), while others have focused on processing speed (Salthouse, 1996).

Finally, others on the link with domain-specific knowledge (Ericsson & Kintsch, 1995) or the efficiency of inhibitory mechanisms (Stoltzfus, Hasher, & Zacks, 1996).

In the past, some studies on working memory capacity have suggested that it can also be related to individual differences in general intelligence, more specifically the Spearman's g (or general reasoning ability). Working memory capacity and Spearman's g share similar characteristics, although they are not identical (Kyllonen, 1996). However, more differential research is needed to further investigate the relation between working memory and g (Conway et al., 2003).

To date, it can be said that there are contrasting lines of research on working memory capacity. One position emphasises the role of cognitive mechanisms which, for example, focus on the total amount of resources, inhibition, and processing speed. Other models have highlighted the relevance of the experience-based factor, such as knowledge and skills (Miyake & Saha, 1999).

1.1.4 Working memory in cognition

The concept of working memory has developed from the concept of short-term (or primary) memory which was thought to be the mechanism for temporary storage of information (Atkinson & Shiffrin, 1968). On the contrary, working memory explains performance requiring the manipulation of information in addition to temporary storage.

Research on working memory has enormously expanded in the last thirty years (Logie & D'Esposito, 2007); with different models of interaction within working memory components and between working memory and long-term memory (LTM) (Woodman & Chun, 2006; Baddeley, 2002; Burgess & Hitch, 2005). To date, many researchers have supported the idea of a strong link between the former and the latter (Baddeley, 2000; Baddeley et al., 2011; Cowan, 2005; Logie & Della Sala, 2003; Ranganath & Blumenfeld, 2005).

Before the first distinction of primary and long-term memory proposed by James (1980) memory was assumed to be a system without separation between short and long-term storage. Research on the mechanism of forgetting due to interference by Müller and Pilzecker (1900) and later on decay with the paradigm of Brown-Peterson (Brown, 1958; Peterson & Peterson, 1959) claimed how the two systems were different. According with these old theoretical positions, in short-term memory system forgetting is an effect of decay whereas in the long-term system is a result of interference. These observations become more clearly defined with the model of Atkinson and Shiffrin on short-term memory (STM). Their short-term memory model (Atkinson & Shiffrin, 1968, 1971), called the **Multi-Store Model,** functioned as a store for information and a gateway to long-term memory. This model describes memory as divided in three different components: a sensory register composed by multiple register for each sense, where the information is captured by senses; a short-term store, which takes inputs from both the other two stores; and the long-term store, where information from short-term memory is transferred only if it is rehearsed.

The model is now regarded to be oversimplified describing short-term and long-term memory as single domains. Baddeley and Hitch (1974) included different components such as the central executive, the phonological loop and the visuo-spatial sketch pad in their working memory model. At the same time, several classifications of description of long-term memory have been defined, for example semantic, episodic and procedural memory. The multi store model by Atkinson and Shiffrin (1968, 1971) was mainly passive and linear, weaknesses that were later addressed by the Multi Component Model by Baddeley and Hitch (1974). The authors described a model for both temporary storage and manipulation of information where different components are involved. The working memory model of Baddeley and Hitch differed from the Multi-Store Model in several ways. First, they replaced the single short-term memory system with one which comprises initially three interacting separated subsystems. Another substantial difference relates to information processing, as from a sub sequential series of stages, it has evolved into a model which included parallel processes between the different systems (Baddeley, 2010).

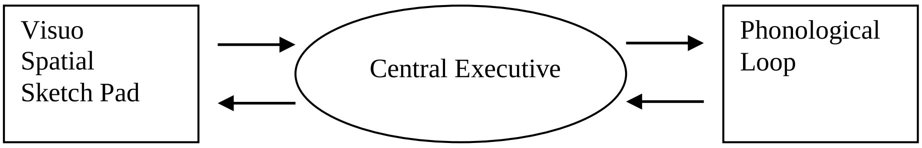
1.1.5 Models of Working Memory

1.1.5.1 Multi Component Model- Baddeley and Hitch

The construct of working memory proposed by Baddeley (1986; Baddeley & Hitch, 1974; Baddeley & Logie, 1999) partly replaced Atkinson and Shiffrin's model of short-term memory (1968). The main difference was a greater emphasis on active manipulation of information rather that passive maintenance. Working memory retained some characteristics of the short-term memory model, for example limited capacity and temporary maintenance of information. This represented a more complex system, as it did not work only as temporary storage, but allowed processing information during the execution of several cognitive tasks. However, the concept of working memory has evolved due to the numerous formulations and reformulations of models proposed by various authors in order to incorporate the evidence into a model. Numerous studies have explored various aspects of working memory (see Baddeley, 2011) from the first model of working memory introduced by Baddeley and Hitch (1974). In the model of working memory by Baddeley and Hitch the emphasis is on the combination of processing and storage as well as the multi component characteristic.

According to the model proposed by Baddeley and Hitch (1974; Baddeley, 1986) (Figure 2), working memory encompasses a broad array of processing and storage functions and works as a combination of different processes. Working memory is composed of the **Central Executive**, which controls, plans and inhibits information while it also coordinates a set of passive stores that maintain information over short periods called "**slave systems**". The two of these that have been extensively researched are the Phonological loop and the Visual-spatial Sketch Pad. The former maintains and processes verbal and acoustic information, while the latter is responsible for the maintenance and manipulation of visual-spatial data.

Figure 1. Original model of working memory (Baddeley & Hitch, 1974).



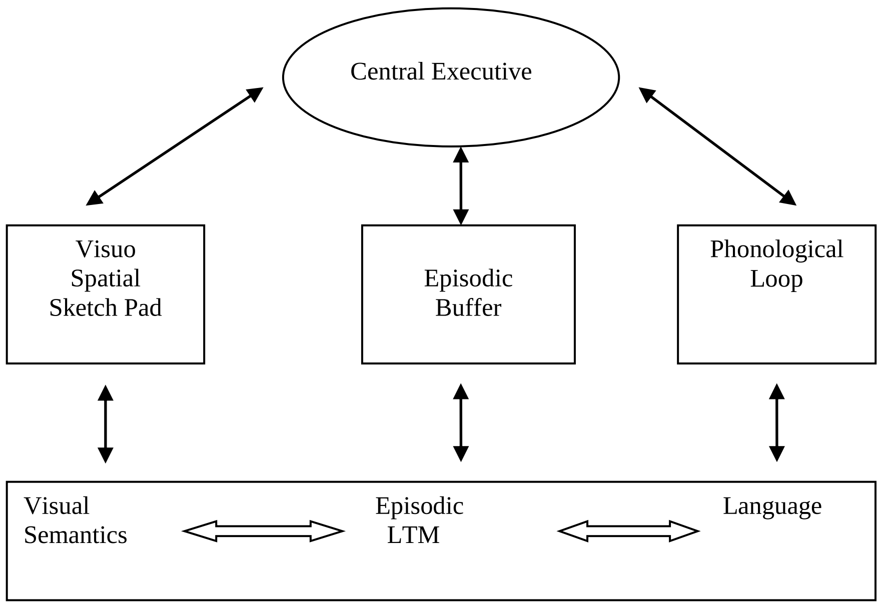
This model was strengthened by empirical evidence both in relation to the dual task technique (for a review see Baddeley, 1997) and from neuropsychological observations (Baddeley & Hitch, 1994). The dual task technique requires participants to perform two tasks at the same time where one absorbs the capacity of one working memory sub system and the other could be a task which requires another working memory proceses, such as learning and reasoning. The dual-task effects have selective impacts based on the sub-system they load on. It has been observed that subjects performing the two tasks show only slight impairment indicating that these tasks require only one of the components of working memory without affecting the others (Hitch & Baddeley, 1976). Studies with healthy adults, using the dual task methodology show that the dual task decrements depend on the nature of the tasks that are performed simultaneously (Cocchini, Logie, Della Sala, MacPherson & Baddeley, 2002; Logie, Della Sala, MacPherson, & Cooper, 2007), and may need to engage additional executive resources to be performed (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). In fact, it has been demonstrated in many studies that impairments in dual task coordination seems to depend on deficit of central executive (Della Sala, Baddeley, Papagno, & Spinnler, 1995; Logie, Cocchini, Della Sala, & Baddeley, 2004).

Similar conclusions regarding the existence of a multi component model of working memory can be drawn from neuropsychological observations. Patients with brain damage or with neurodegenerative disease display double dissociations (Della Sala & Logie, 1993; 2002), for example patients with Alzheimer’s disease (Baddeley, Bressi, Della Sala, Logie, & Spinnler 1991; Baddeley & Della Sala, 1986; Della Sala et al., 1995). Logie and colleagues (2004) performed three studies with Alzheimer’s disease (AD) patients on digit sequence recall and visuo-spatial tracking. They found the AD patients showed a significant dual task deficit compared to younger and older adults subjects. They concluded that there is a clear cognitive system for dual task organisation within the multiple component working memory system. Executive functions seems to be engaged in the coordination of concurrent task performance (Logie et al., 2004). In a study carried out by Della Sala, Cocchini, Logie, Allerhand and MacPherson (2010) patients with Alzheimer's disease display a substantial dual task decrease in comparison to healthy controls. The authors speculated that in Alzheimer's disease patients there is an impaired mechanism for coordinating the simultaneous performance of two tasks. The impairment seems to emerge during the retrieval phase; even through the performance during retrieval and encoding is not statistically dissimilar (Della Sala et al., 2010). Evidence for the separability of verbal and visuo-spatial systems is also present in patients with Alzheimer's disease who clearly show double dissociation in verbal and visual memory span with selective deficits (Baddeley, Della Sala & Spinnler, 1991).

This original model did not address other relevant relations such as the links between working memory and long-term memory, and between the slave components (Baddeley, 2007). These relations between different components of the model were introduced in the new updated model (Baddeley, 2000).

There is evidence which supports the existence of links between the two sub systems, specifically when a stimulus has to be remembered both for its locations and for its verbal content (e.g. Smith et al., 1996; Baddeley et al., 1984; Quinn & McConnell, 1996). In order to take into account this evidence, Baddeley (2000) has expanded the model, with the addition of the **Episodic Buffer (EB)** (Figure 3), a component capable of integrating the information coming from the two sub-systems of working memory with long-term memory (LTM), under the control of the Central Executive in the initial theorisation (Baddeley, 2000). A number of observations indicate that 'bound' representations of such stimuli are indeed formed in memory (e.g. Allen et al., 2006; Allen et al., 2009; Baddeley et al., 2009; Bao et al., 2007; Karlsen et al., 2010). The latest version of the working memory model by Baddeley and colleagues (2011) is characterised by many forms of binding as developing within the episodic buffer but without the intervention of executive attentional processes. Initially, the episodic buffer was considered attentionally demanding in his binding role, but later it has been proposed to have a passive rather than active storage function (Baddeley et al., 2009). According to this model, the sub systems, phonological loop and the visuospatial sketchpad, can all receive information from both the long-term memory and from sensory input (Baddeley, 2002) forming an active store.

Figure 2. The working memory model with the introduction of the Episodic Buffer (EB; Baddeley, 2000).



1.1.5.1.1 The phonological loop

The phonological loop is considered an important system in language comprehension, acquisition and reading (Baddeley, Gathercole, & Papagno, 1998). It is composed of a phonological store and an articulatory control process. The phonological store holds speech information for few seconds and it can be refreshed by the articulatory process able to convert data from a visual to a phonological code (Baddeley, 2007).

The phonological loop also explains several short-term effects such as the word length effect, the similarity effect (Baddeley, 2003), the articulatory suppression and irrelevant speech (Andrade, 2001). The first one, the *similarity effect*, represents the difficulty to recall phonologically similar words (or letters) rather than dissimilar (Larsen, Baddeley & Andrade, 2000). In contrast, semantic or visual similarity have only a small effect (Conrad & Hull, 1964) that can be explained by the time needed to subvocally rehearse each item (Baddeley, Chincotta, Stafford & Turk, 2002). The *word length effect* describes why it is easier to recall shorter instead of longer words as it takes more time to rehearse and to reproduce longer items (Baddeley, Thomson & Buchanan, 1975). *Articulatory suppression* explains that preventing articulation of items to be remembered with an aloud repetition of irrelevant words or sounds (such as "the") interferes with short-term memory for verbal material. Thus the performance declines strongly, blocking the subvocal rehearsal (Larsen & Baddeley, 2003). Articulatory suppression does not interfere with visual items (Smyth, Pearson & Pendleton, 1998) and removes the effect of word length with both auditory and visual materials (Baddeley et al., 1984). The last effect of the phonological loop is the *irrelevant speech* which negatively affects the performance on serial recall of verbal material because of concurrent and irrelevant sounds, especially words with the same phonemes (Salamé & Baddeley, 1982). These observations show that sounds of speech have obligatory access to the phonological store, supporting the idea that information in this store is codified in a phonological, rather than semantic way (Andrade, 2001).

Another phenomenon of the phonological loop is the *transfer of information between codes* (Baddeley, 2000). In this case the transfer is from a visual to auditory codification, which explains how subjects visually rehearse presented items in a subvocal way. This effect is removed by articulatory suppression (Murray, 1968).

The role of the phonological loop, with distinct storage and rehearsal components, is strongly supported by neuropsychological evidence (Della Sala, & Logie, 2002; Baddeley, 2003). First, patients with anarthria, which is the inability to produce speech sounds, can rehearse and show immediate verbal recall sensitive to the length of words, suggesting that phonological loop works independently from the speech production system (Baddeley & Wilson, 1985). Important information about the independent functions of phonological storage and rehearsal system are obtained from patients with acquired neuropsychological deficits, like patient PV described by Vallar and Baddeley (1984). PV was described as suffering from a specific verbal short-term memory impairment but with a normal written language, speech production and articulation rate. PV could use the phonological similarity when auditory (but not visual) stimuli were used. Her performance was slightly impaired for visual materials which did not benefit from articulatory suppression, word length and phonological similarity. It is a significant example of a specific impairment of the phonological short-term store. Other relevant examples come from aphasic patients with dyspraxia, a developmental coordination disorder (DCD) that may affect speech motor codes fundamental for articulation. These patients, despite their articulatory difficulties, display an adequate capacity for rehearsal (Baddeley & Wilson, 1985).

1.1.5.1.2 The visuo-spatial working memory (VSWM)

Visuo-spatial working memory was initially referred to as visuo-spatial sketch pad (Baddeley & Hitch, 1974). It was subsequently changed to visuo-spatial scratch (VSSP) pad in order to avoid the misinterpretation of a system that could handle only pictorial information. Visuo-spatial sketchpad is then a system responsible for storage and manipulation of all the visual and spatial material (Baddeley, 1986). This can be referred to as visuo-spatial working memory (VSWM) in a more generic way to describe the function of this system.

The function of this system is important for mental synthesis, acquisition of semantic knowledge and spatial orientation (Baddeley, 2003) as well as for storing verbal material in a visual coding. This last function was observed in studies where subjects were asked to recall the correct sequences of letters appearing in either upper or lower case (Logie, Della Sala, Wynn, & Baddeley, 2000). The interesting manipulation made in this specific study was the visual similarity of letters, as it_indicated that participants showed more difficulties recalling case form of visually similar sets. This result indicates the benefit of using visual code for verbal items, which has been confirmed by other studies (Logie et al., 2000). The *visual similarity effect* appears in normal adults and young normal children of visually presented materials, supporting the presence of a visual temporary memory system. This effect has not been examined as thoroughly as the phonological similarity effect and seems to be weaker (Logie, 1995).

Another relevant observation about visuo-spatial working memory is found in a study conducted by Baddeley and Lieberman (1980), which indicates that this system comprises visuo-spatial retention, visuo-spatial perception and motor control. The term visual is used for the appearance of an object (shape, colour, dimension and brightness for example) and its location in relation to a particular prospective. "A visual representation in working memory might involve retention of static visual arrays which incorporate geometric properties of the layout of objects or the relationship of the parts of a single object to one another" (Logie, 1995; p. 78). On the other hand, the term spatial describes the sequence of movements or changes in the perceived location, incorporating imagined movements as well (Logie, 2003). “It could also involve building up a representation of the geometric relationship between objects by scanning from one to another or moving from one to another” (Logie, 1995; p. 78). Visuo-spatial working memory can thus be subdivided into two different components for visual and spatial information with evidence from experimental psychology and neuropsychology supporting this view. Patients with brain damage show a double dissociation of visual and spatial short-term memory with selective impairments for one of the two components (Wilson, Baddeley, & Young, 1999; De Renzi & Nichelli, 1975). There are patients who show difficulties in visual working memory while performing normally in spatial working memory tasks, without impairments for movement sequences, location recall and rotation tasks. On the contrary, there are patients with preserved visual working memory and impaired spatial memory (Pisella, Berberovic, & Mattingley, 2004; Carlesimo, Perri, Turriziani, Tomaiuolo, & Caltagirone, 2001). Other neuropsychological observations reported epileptic patients with right hemisphere ablation with impaired spatial memory and intact verbal working memory (Milner, 1965; Corkin, 1965).

Additional evidence of the separation between visual and spatial working memory has been reported in studies with healthy subjects (Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999). In this study the double dissociation has been assessed with selective interference using Corsi Blocks Tapping test (Spinnler & Tognoni, 1987) for spatial performance and the Visual Pattern test (VPT; Della Sala, Gray, Baddeley, & Wilson, 1997) for a visual secondary task. This has provided further evidence for the distinction and improved knowledge for the function of the visuo-spatial working memory (Darling, Della Sala, & Logie, 2007; 2009).

1.1.5.1.3 The central executive (CE)

The central executive is a non-unitary (Baddeley 2007), attentional controller which coordinates the two sub systems, the phonological loop and the visuo-spatial scratch pad, and is responsible for focusing and dividing attention (Baddeley, 2003). It had similar characteristics to the supervisory attentional system (SAS) proposed by Norman and Shallice (1986).

In the first model of working memory by Baddeley and Hitch (1974), this component was thought to be involved both in storage and control process as well as in decision making. This model was then revised with the dual task paradigm which demonstrated that storage and processing tasks do not compete for a unique resource (Cocchini, Logie, Della Sala, MacPherson & Baddeley, 2002). The main function of the central executive is the capacity to direct and focus attention (Baddeley, Eysenck & Andreson, 2009), as well as divided attention among several tasks (Baddeley, 1996).

An important technique used in studies on the central executive is random generation, which selectively burdens this component, interfering with the switching from one task to another (Baddeley, 1998). Other studies on the central executive have been carried out assessing patients with Alzheimer's disease (AD) who seem to have a specific damage of the Central Executive, especially in dividing their attention on difficult tasks (Baddeley et al., 1991; Baddeley et al., 1991; Baddeley, Logie, Bressi, Della Sala, & Spinnler, 1986). This specific form of impairment has been assessed using the dual task paradigm where participants are asked to perform two tasks at once (Logie, Cocchini, Della Sala & Baddeley, 2004; Baddeley & Della Sala, 1996). In these experiments a specific impairment in the central executive has been observed in patients with Alzheimer's disease, which correlates with behavioural difficulties (Baddeley, Della Sala, Grey, Papagno & Spinnler, 1997) and problems performing daily activities that require dual-tasking, such as "walking while talking" (Cocchini, Della Sala, Logie, Pagani, Sacco & Spinnler, 2004) or "keeping track of conversations" (Alberoni, Baddeley, Della Sala, Logie & Spinnler, 1992). These observations indicated that Central Executive is involved in tasks that require attention to switch among more tasks, such as following a conversation with a number of people taking part.

Apart from switching from one task to another which does not seem to be based on a single executive subprocess (Baddeley, 2007), there are other important roles covered by the central executive, such as time sharing in dual task performance, selective attention and the capacity to integrate working memory with long-term memory (Baddeley, 1996, 2007; Eysenck & Keane, 2000). One of the central characteristics of working memory is to focus and drive attention through the central executive. Even though it is well-known that the system has a limited capacity, it can be possible to perform two different tasks at the same time, as in expert pianists who are able to read, play and shadow prose (Allport, Antonis & Reynolds, 1972). The fact that attentional system has a limited capacity, which is not linked with the difficulty of the task (Logie et al., 2004), is well established (Miller, 1956; Broadbent, 1958) and accepted by current attentional theories (Pashler, 1998). Moreover, the demand for attentional control is reduced with practice and strategy adopted (Baddeley, 2007).

Central executive is now not considered as a unitary component since that several higher cognitive functions have been referred to it (such as problem solving, updating, comprehension, retrieval, reasoning, inhibition, learning and switching) (Logie, 2015). According to a recent paper by Logie (2015) it seems that executive control could be a combination of various cognitive functions that may use distinct and overlapping brain networks.

1.1.5.1.4 The episodic buffer (EB)

The most recent component which has been added to the model of working memory model is the episodic buffer (EB; Baddeley et al., 2011). "The system is episodic in the sense that it integrates information into coherent episodes; it is a buffer in that it comprises a limited capacity storage system that enables information coded using different dimensions to interact" (Baddeley, 2007, p. 148).

The episodic buffer is a temporary storage system which combines information from the two sub systems, the phonological loop and the visuo-spatial sketchpad, the information from sensory systems (including smell and taste) and long-term memory in a meaningful representation. The main role of the episodic buffer is binding information into chunks from different systems, and this makes it limited in the number of chunks that it can maintain (Baddeley, 2007).

Reflecting on the development of the model of working memory, it can be noticed that the original multi-component model by Baddeley and Hitch (1974) has been significantly modified two times in order to integrate the new data of binding explained by the new component, the Episodic Buffer (Baddeley, 2000; Baddeley et al., 2011). The first three-component model (Figure 1) described the central executive as a limited capacity controller of the two temporary storage systems, which could store and manipulate information. Subsequently, the idea of the central executive playing a storage role was abandoned (Baddeley & Logie, 1999). Therefore it became necessary to add the forth component, the Episodic Buffer (Figure 2), in order to account for a range of functions and processes that could not be explained by the initial model. Initially the EB was postulated to be "a temporary multidimensional store that forms an interface between the subsystems of working memory, long-term memory and the central executive" (Baddeley et al., 2011; pp. 1393- 1400). The EB was hypothesised to be a limited capacity component that relies strongly on executive processing. The difference with the central executive is that the EB is mainly concerned with the storage rather than with attentional control of information which is limited. This multidimensional component, accessible through conscious awareness, binds together information with different codes and sources; creating limited numbers of meaningful chunks into a single multi-faceted code (Baddeley, 2003). It has been proposed that automatic filtering mechanisms operate in order to select which characteristics are held as bound representations (Ueno, Mate, Allen, Hitch, & Baddeley, 2011) through the support of long-term memory and without attentional control (Baddeley et al., 2011). The episodic buffer is thought to bind items into units with a meaning and cues which help to access representations stored in long-term memory. Chunking information together gives a meaningful association to the individual item which can then be linked to stored representations in long-term memory. The episodic buffer seems to be a component which combines visual, auditory, smell and taste information (Baddeley, 2010). This revised model better explains the interactions in a multidimensional code between the different components of working memory with specific coding systems and the link with long-term memory.

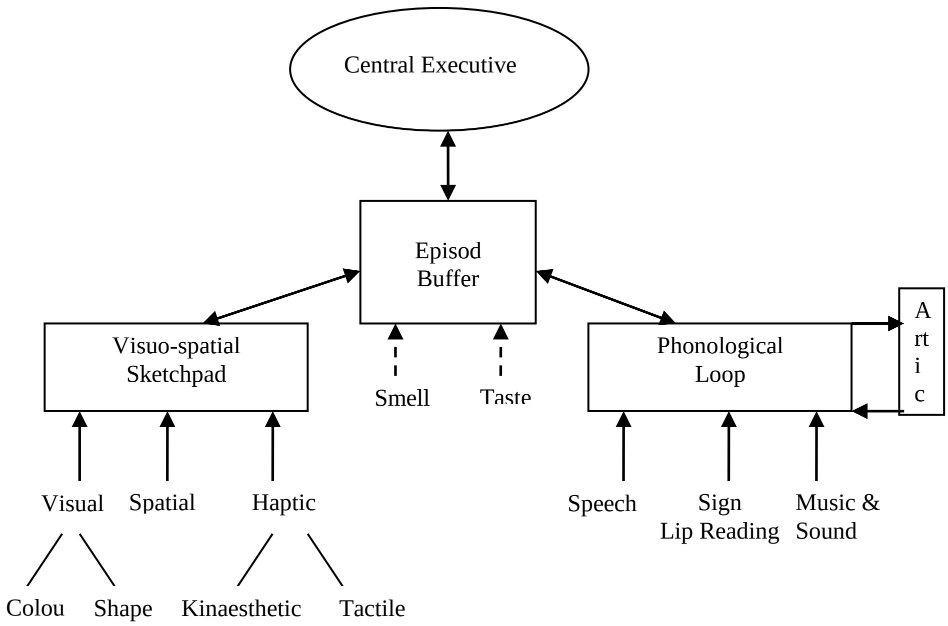
One of the reasons for incorporating the episodic buffer into the model was to explain how the phonological loop and visuo-spatial sketchpad could interact. In the review of their earlier work Baddeley, Allen and Hitch (2011) decided to test their conclusions investigating binding in two different paradigms: the binding of features (visual working memory) and the binding of words (in the comprehension and retention of prose). Studies of prose recall highlighted the need to add a further component to the model. It has been observed that the prose span can have a capacity of more than sixteen items, in contrast with word recall span which normally has a limit of approximatly seven. This is due to the ability to chunk, which makes it possible to combine several words in a small group according to the information coming from long-term memory and this function could not be explained by the old model (Baddeley, 2000). As a consequence, the episodic buffer was proposed to account for these observations. It has been suggested that the episodic buffer could be the component which is responsible for prose recall. This conclusion is supported by studies with amnesic patients who performed normally in immediate

memory for prose tasks (Baddeley & Wilson, 2002). The binding of words into chunks seems to be an automatic process; also involving long-term memory and does not depend on the central executive (Allen & Baddeley, 2008; Baddeley et al., 2009). This conclusion about the role of the central executive changed from previous assertions by Allen and colleagues (2006) where the episodic buffer was described as central executive-dependent. Initially, the author (Baddeley, 2000) claimed that access to the episodic buffer, from the phonological loop and visuo-spatial scratch pad, takes place through the central executive and is dependent on general attentional resources. In this context, the episodic buffer was assumed to be strongly linked with the central executive and there was not direct links between the phonological and visuo-spatial subsystems. However, the original conception of episodic buffer has been recently changed. While initially it was conceived reliant on executive control (Baddeley, 2000), it has been demonstrated that it can work automatically, being independent from attentional load (Baddeley et al., 2011).
The other line of research has focused on investigating mechanisms of binding in visual working memory (Allen et al., 2006). The term binding is used to describe the phenomenon of grouping together different characteristics of an object such as shape and colour. Baddeley and colleagues (2011) argued that the visuo-spatial scratch pad can be considered as a hierarchical system which incorporates both feature and object levels of representation where binding of visual characteristics develops. The episodic buffer then retains and manipulates the results of this process.

1.1.5.1.5 The latest version of the multi component model of working memory model (Baddeley et al., 2011)

Taking into consideration studies conducted on the working memory model, the latest version emphasises the role of the episodic buffer as “a purely passive system. But also one that serves a crucial integrative role because of its capacity to bind information from a number of different dimensions into unitised episodes or chunks” (Baddeley et al., 2011, pp. 1393-1400). It has also been hypothesised that taste and smell can have access to the episodic buffer, even though there is not clear evidence of this. To date, it is thought that the episodic buffer mediates the conscious access to the phonological loop or sketchpad. At the same time the visuo-spatial system is believed to combine spatial, visual, tactile and kinaesthetic information, while the phonological loop links different kinds of language-related information (Rönnberg, Rudner, & Ingvar, 2004) (Figure 3).

Figure 3. The revised model of working memory (Baddeley et al., 2011).



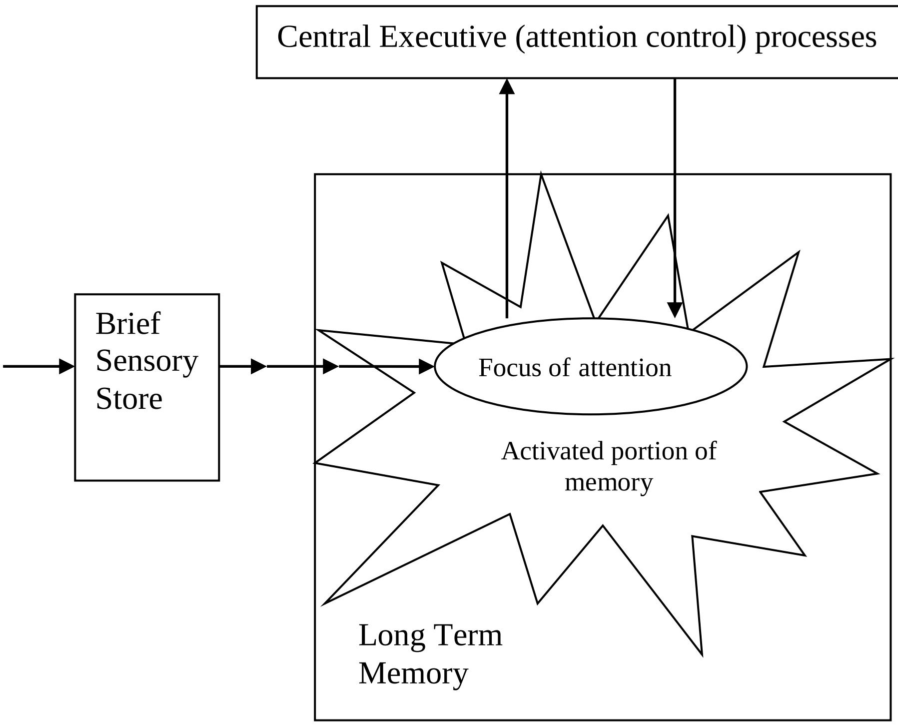
1.1.5.2 Cowan's Embedded-Processes Model

The Embedded-Process model by Cowan (1988, 2001, 2005; Figure 4) hypothesises that information in long-term memory can exist in varying states of accessibility according to the level of activation. This model rejects the idea of separate stores for short and long-term memory, advocating a unitary view of memory, also called "monistic view' (Cowan, 1995), or 'proceduralist view' (Crowder, 1993).

Some researchers have questioned the assumption that short-term memory and long-term memory are separate cognitive systems (Postman, 1975; Neath, Brown, Poirer & Fortin, 2005; Ranganath & Blumenfeld, 2005), supporting the unitary view of memory. They postulated that both systems of memory act as a single unitary system and rather than describing memory as a set of distinct specific stores for different tasks, define it as a continuous process. Several models of working memory are based on the idea that short-term memory can be activated by long-term memory (Logie & D'Esposito, 2007; Osaka, Logie & D'Esposito, 2007). The 'controlled attention' framework by Engle (Engle, 2002; Barrett, Tugade & Engle, 2004) is one of those models and focuses on the individual differences in working memory capacity. According to this model, long-term memory requires executive control to take and maintain representations into focus.

The most influential model which supports the unitary view is the embedded process model by Cowan (1988; 1995; 1999; 2005; Cowan, Morey, Chen, & Bunting, 2007).

Figure 4. Embedded-Processes model by Cowan (1988; 1995; 1999; 2005).



Cowan (2005) developed his model in a different way to the multi storage model. Short-term memory store is included in long-term memory and perceptual information goes through the sensory storage. In this model an important role is played by attention, which has a limit of four chunks, and by long-term memory where temporally activation occurs. This activation can dissipate except when is maintained with attention or verbal rehearsal (Cowan, 2005).

The *sensory storage* of visual and auditory domains occurs in two stages. The initial phase, experienced as sensation, lasts for several hundred milliseconds and the second one continues for few seconds. This last phase creates the rich memory of the stimulus (Cowan, 1988). In the first phase the stimulus is not elaborated while in the second stage the information is partially analysed. In this model both sensory memory and short-term memory are limited in their capacity, while both possess similar coding systems and can store information outside of awareness (Cowan, 1988).

Cowan describes working memory as a system which allows the retention of information which become available when required. The components of his model are long-term memory, the activated long-term memory or short-term storage and the focus of attention (Figure 4).

The *focus of attention* is the activated subset of long-term memory and it is linked with central executive processes in order to deal with different stimuli from the environment. Semantic stimuli are activated by the focus of attention (Conway, Cowan, & Bunting, 2001), whereas sensory stimuli, either familiar or novel, may be directly activated. The unfamiliar stimuli activate attention, while the familiar are directed to the short-term store, which is the activated long-term memory (Cowan, 1988; Cowan et al., 2007). Information can be consciously noticed when attention is focused on one stimulus. In this case, information is subsequently activated in long-term memory and influences voluntary actions. Actions can be also influenced by information not consciously perceived. (Cowan, 1995). As a consequence, it seems clear that information more readily available in working memory is the one under the focus of attention (Cowan, 1999). The limits of the focus of attention is hypothesised to be on average four items or chunks (Cowan, 2005).

The other component of the embedded process model is the *central executive,* a limited capacity control process which guides voluntary attention as well as voluntary retrieval and activation of information from long-term storage (Cowan, 1988; Cowan et al., 2007). This component of the system is always connected with long-term memory which activates items in the focus of attention, and with short-term retention and manipulation of information. Short-term retention allows to focus on long-term memory information under the focus of attention. This prevents non-relevant items from interfering with a specific task. Cowan described this as an inhibitory process which enables working memory to be focused on information relevant for a certain task (Cowan et al., 2007). The central executive has a limited focus of attention. Limited information can be maintained as attention is shared between new external stimuli and long-term information (Cowan, 1988).

Another component of this model is the *short-term storage* which has a limited capacity and functions similarly for different kinds of information, for instance phonological and visual. The theory regarding short-term memory is in contrast with the one proposed by Baddeley (2003) in which storage is described as modality-specific for visual and phonological information (Baddeley, 2003; Cowan, 1988; 2001). Hence the embedded-processes model is compatible with the unitary view of memory described above, which does not postulate separate structures in short-term memory (Cowan et al., 2007). According to this model (Cowan, 2008), short-term memory is conceived as a temporarily activated subset of information included in long-term memory which can decay except the information is refreshed, while the focus of attention is a subset of the activated information, which has a limited capacity (Cowan, 2008).

The definition of working memory by Cowan is analogous to the view of Engle (2002), but with a more complex conception. Although the focus of attention is thought to be essential by Engle and colleagues, Cowan, referring to the capacity limits, claimed that "the control of attention is relevant, but there is an independent contribution from the number of items that can be held in attention" (Cowan, 2008; p. 12).

There are a number of incongruities in this model which do not account for several phenomena such as the possibility for short-term memory and long-term memory to be impaired separately. On the basis of this observation, Baddeley (2007) questioned the relation between the two systems, further investigating the modalities in which long-term memory is connected with short-term memory. According to Cowan (2008) the two subsystems, phonological loop and visuo-spatial sketchpad, are considered as part of activated memory whereas episodic buffer (Baddeley, 2000) is similar to the information under the focus of attention. Baddeley (2010) and Cowan have agreed on many aspects of their models, even though the focus is on different components, with the former emphasising the role of short-term verbal memory and the latter focusing on attention.

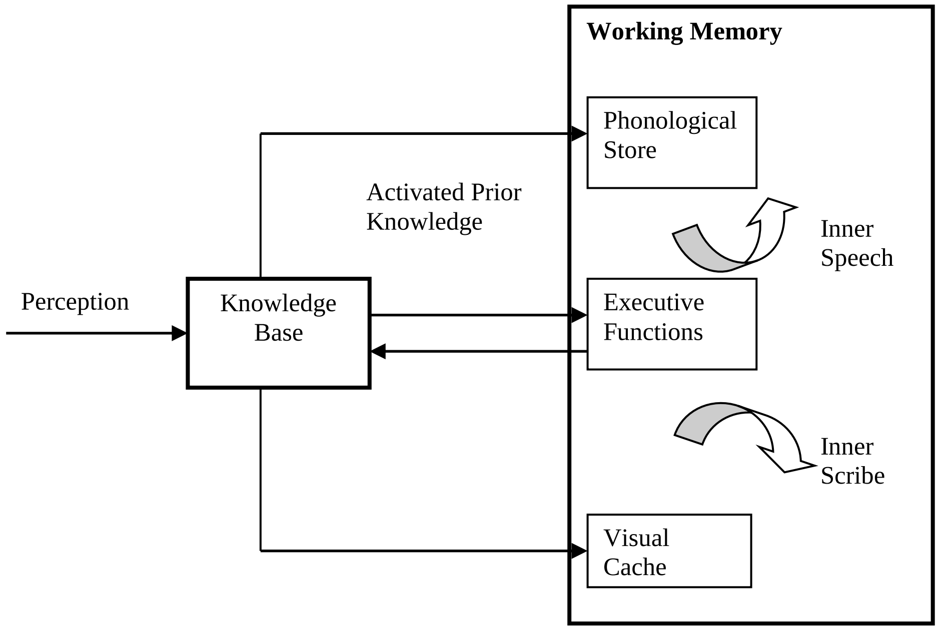
1.1.5.3 Mental Workspace Model - Logie

The working memory model proposed by Logie (1995, 2003) describes working memory as a mental workspace which maintains and manipulates online data. This process is different from long-term memory but interacts with information already stored from previous experiences (Logie & Della Sala, 2003). According to the workspace model, initially perceptual information enters in the “knowledge base”, activating long-term memory and then involving working memory, which has a separate system (van der Meulen, Logie, & Della Sala, 2008) (Figure 5). This model has been developed to account for several problems with the other models discussed above and to combine the descriptive multi-component model of working memory (Baddeley, 2003) with the unitary model, which describes the relation between working memory and long term-memory and their mutual activation (Cowan, 1988; 2005).

In the mental workspace model, working memory and long-term memory are considered as separate. The perceptual information enters in long-term memory before accessing working memory, unlike the unitary model proposed by Cowan. However, long-term memory can also be stimulated by working memory without perceptual stimuli (Logie, 1995; 2003). In this context, working memory is then considered as an independent mental workspace which is activated by long-term memory and it is involved in maintaining and manipulating information, both verbal and visuo-spatial.

According to this perspective, perceptual stimuli have to be elaborated through long-term memory, otherwise they would result in raw sensory information in working memory, without specific meanings or connotations. As a consequence, working memory is not described as a stage which precedes the elaboration of long-term memory. On the contrary, this model assumes that information needs to be associated with a precise connotation and interpretation in long-term memory before any manipulation can occur in working memory (Logie, 2003). These observations are consistent with the evidence that stimuli in working memory are elaborated and identified according to long-term memory (Barquero & Logie, 1999).

Figure 5. The mental workspace working memory model by Logie (1995; 2003).



It is clear that this model has several *differences with the multi component model*. One of the main weaknesses of Baddeley model pointed out by the workspace model is the anomaly in processing semantic information when stimuli are implicitly perceived (Della Sala & Logie, 2002; Logie, 2003). Consequently long-term memory should be activated without the involvement of working memory, but this phenomenon is not accounted for by the multi component model. This last model uses the observation that semantic information of visual inputs can be perceived without conscious elaboration to support the idea that stimuli are initially elaborated in long-term memory (Logie, 2003).

Moreover, another complication of the multi component model is the difficulty in clearly explaining the double dissociation of impairment in working memory and perception in the verbal and the visuo-spatial domains. At the same time, one of the objections towards the model presented by Baddeley is the failure in explaining selective impairments of verbal and visuo-spatial working memory when perception and long term memory are unimpaired (Denis, Beschin, Logie, & Della Sala, 2002). The multi component model seems to have difficulties in accounting for conditions in which long-term memory is intact and working memory is impaired (Della Sala & Logie, 2002).

At the same time, the workspace model has several *differences with the unitary model* (Cowan, 1988). First, it challenges the approach in describing the relation between working memory and long-term memory. It has been highlighted that working memory cannot clearly account for the complex properties of storage and processing of working memory, as well as other several cognitive processes, such as binding (Baddeley, 2003) and dual task interference (Logie & Della Sala, 2003). The multi component model of working memory by Baddeley describes working memory as capable of processing and maintaining information rather than a component which is only a passive temporary store. Finally, one objection that can be addressed to the workspace model concerns the idea that perceptual information can only reach the working memory system passing through long term memory (Baddeley, 2007). This can also occur for new information which does not have a stored representation in the "knowledge base" system. Working memory should act as a workspace to generate new information if the stimuli that enter long term memory are not complete (Logie, Engelkamp, Dehn, & Rudkin, 2001). The role that Logie (2003) ascribes to working memory is to create and manipulate new data which increase our knowledge.

1.1.6 Other Working Memory models

1.1.6.1 The Three-Embedded-Components Model - Oberauer

The declarative and procedural computational model of working memory by Oberauer (2002) is similar to the one by Cowan (1999). It considers information according to various states with the most recently activated memory items being more readily accessible. On the other hand, it differs from the Cowan model for the capacity of the component. In this model, only one chunk or item can be in the centre of focus, unlike the four items postulated by Cowan (2010). A similarity between the two models concerns working memory as an activated component of long-term memory. Oberauer (2009) describes his recent model "as a connectionist model with two modules, an item-selection module and a set-selection module. The architecture is intended as a model of both declarative WM and procedural WM" (Oberauer, 2013; p.2). Declarative working memory indicates concepts such as symbols and objects, whereas procedural working memory refers to actions.

1.1.6.2 The Controlled Attention Framework model- Engle

Engle and colleagues (Engle et al., 1999a; Kane & Engle, 2003) define working memory as the sum of STM (Short-Term Memory) and attentional control. Attentional control can be used to activate traces from long-term memory through controlled retrieval, to maintain such activation through various ways or to reduce the activation through inhibition. The use of the term attentional control is derived from the construct of supervisory attentional system by Shallice (1988; Norman & Shallice, 1986), which intervenes between different objectives of the task, external stimuli and patterns of well-learned responses (Kane & Engle, 2003). Short-term memory in this model consists of the enabled information in long -term memory; such activation is reduced as a result of decay and/or inhibition. Traces of short-term memory are primarily phonological or visual, but they may have other formats. However, all types of traces obey the same principles of forgetfulness and interference, regardless of their format. Only a small number of these traces are activated above the threshold on the basis of relevance to the objectives of the task that is taking place. It is interesting to note that, similar to the model by Baddeley and Hitch (1974), working memory can be defined as a system composed of a component of maintained information and an attentional component. The only difference is that in the model of Engle and collaborators (Engle et al., 1999; Engle et al., 1999a) the concept of short-term memory has been included, and is considered as a sub system (articulatory loop and visuo- spatial sketch pad).

Engle et al. (1999) specify that working memory capacity is generally thought of as attentional control. The authors compare this attentional mechanism to the limited capacity of the central executive by Baddeley and Hitch (1974). The ability of working memory does not refer to the memory itself, or at least not directly, but to the ability to use attentional control to maintain information relevant to the task despite distraction or interference. In other words, a greater capacity of working memory is the result of the ability of attentional control, and not of a wider memory system. The measures of working memory capacity are based on tests in which participants are asked to perform a task; such as reading phrases or doing mathematical operations, and simultaneously to keep in mind a growing list of words. Such measures appear to be predictive of performance in a wide variety of daily cognitive tasks, including understanding texts (Daneman & Carpenter, 1980), reasoning (Kyllonen & Christal, 1990), the ability to follow directions (Engle, Carullo & Collins, 1991) and more generally fluid intelligence tests (Engle et al., 1999a). Engle (2002) argues that individual differences in measure of working memory reflect the differences in the ability to control attention in order to keep the information active and easily retrievable, particularly in situations of distraction or interference. These differences, therefore, will be evident in situations where attentional control is necessary, or a) when the goals of the task may be lost if they are not kept active in working memory; b) when more actions compete for a specific answer or when a response must be programmed; c) when it has to resolve conflicts between actions in order to avoid errors; d) when it is important to maintain some information about the task in the event of interference or distractions; e) when it is important to suppress irrelevant information for the task; f) when the monitoring and correction of errors require control and effort; g) when it is useful, controlled and planned research between the contents of the memory (Engle et al., 1999a).

Working memory represents the capacity to maintain a memory representation in spite of interference and distractions (Kane & Engle, 2003). This seems to be strongly linked with executive attention which is crucial to predict performances on high cognitive domains (Engle & Kane, 2004) and fluid intelligence (gF) (Unsworth, Spillers & Brewer, 2009).

1.1.6.2.1 The Dual-Component Model of working memory - Unsworth and Engle

The dual-component model of working memory by Unsworth and Engle (2007) considers the term working memory similarly to long-term memory. This model has used the concepts of primary and secondary memory already adopted by Atkinson and Shiffrin (1971), theorising that working memory is involved in both components (Unsworth & Engle, 2006). The authors claim that a limited amount of information can be maintained by primary memory and, once its capacity has been exceeded, secondary memory is activated. The dual-component model hypothesises that primary and secondary memory are both involved, with distinct activated levels depending on different kinds of immediate recall tasks. In this model both primary and secondary memory are required in both simple and complex span tasks. However, simple span tasks such as digit span mainly use primary memory. When the list of digits to remember is larger than four chunks, secondary memory is also activated. For instance, for complex span tasks such as reading or operation span, (reading sentences and solving math problems), the engagement of secondary processing is required.

1.1.6.3 The Continuous Conical Model - Cornoldi and Vecchi

Cornoldi and Vecchi (2000; 2003) have suggested a more flexible model based on two continuous dimensions based on evidence that there are processes of working memory which are not clearly attributable to a specific system. One of the dimensions is vertical and the other horizontal, and they can be represented by a diagram composed by cones. The processes of working memory, in fact, vary based on the amount of active processing of information required for a task and the nature of the information to be processed. The vertical dimension is the continuum of the active control associated with a particular cognitive task. This continuum ranges from processes which are totally passive, requiring little or almost no attentional control (which can be compared to the subsystems of the multi-component model), up to increasingly active processes required in extremely demanding tasks (similar to the role of central executive system). It has to be taken into account that a task cannot be defined exclusively as active or passive, since each process may be assigned a different level of control.

The horizontal continuum, however, is linked to the specific nature of perceptual input. At one end there is spatial information, with the verbal domain on the other end of the continuum. Those are linked through peripheral systems which connect visual and tactile materials. It must be emphasised there are no discrete subsystems which are specific for each type of material, rather the model suggests a continuous dimension with systems more or less distant from each other. This means that the visual and spatial characteristics are close along the continuum. Conversely, the visual-spatial and verbal information are not directly in contact along the continuum. This is the reason why the distinction between verbal and visual-spatial subsystem is quite clear. The horizontal continuum receives sensory information, but is also connected with representations stored in long-term memory that can be used for automated tasks. Finally, the horizontal dimension interacts with the vertical. This means that the differences between specific mode processes are not present only at peripheral levels, but may find themselves at each level of the vertical continuum.

Experimental evidence in favour of a model of working memory that postulates the existence of two separated continuum processing comes from a series of studies based on individual differences (Vecchi, 1998; Vecchi & Cornoldi, 1999; Vecchi & Girelli, 1998). For example, Vecchi and Cornoldi (1999) have administered a series of tasks of verbal and visual-spatial working memory, both active and passive, to three different groups of age (young, elderly and very old). According to the authors, the difference between young and old seems to be attributed to a reduced ability to cope with active tasks by elderly people. One related to the material (verbal and visual-spatial) and another linked to the specific characteristics of the task (passive or active) (Cornoldi & Vecchi, 2000; 2003). Finally, studies on gender differences found that males tend to achieve superior performance than females in visual-spatial tasks (Vecchi & Girelli, 1998).

Compared to the multi-componential model (Baddeley, 1986), the model of working memory proposed by Cornoldi and Vecchi (2000; 2003) allows the assigning different degrees of control to tasks in different modalities.

1.1.6.4 Time-based resource-sharing- Towse et al. and Barrouillet

More recently, two developmental theories of working memory have been proposed: the theory by Towse (Towse, Hitch, Hamilton, Peacock & Hutton, 2005) and the other by Barrouillet (Barrouillet & Camos, 2001). Such theories explain the increase, with age, of working memory capacity.

For Towse the ability of working memory depends more on the duration than the difficulty of the secondary task (dual task). The increase of the span with age is due to the progressive development of the speed of processing information in older children. Towse has created a paradigm for the measurement of the "memory period": unlike that in the span, the number of items to remember remains constant, while the time necessary to process every single item varies. Towse has thus demonstrated that the storage period is closely related to the span: the capacity of memory is lower when the retention time of the material to remember increases. This phenomenon is present in the developmental stage, as it has been seen from longitudinal studies with children (Hitch, Towse & Hutton, 2001). Towse has thus stressed the importance of the processing time, apart from the capability itself, in determining the performance of working memory tasks (Towse et al., 2005).

The TBRS model (Time-Based Resource-Sharing) by Barrouillet and colleagues (Barrouillet & Camos, 2001; Barrouillet, Bernardin & Camos, 2004; Barrouillet & Camos, 2007) is based on four main assumptions:

1. The two main functions of working memory, processing and maintenance, draw on the same limited attentional resources.
2. Only one attentional process is allowed by the central processes at any given time. As a consequence, when attention is engaged in processing, it is not available for maintenance and storage processes.
3. When attention shifts from processing in favour of maintenance process, the latter changes with time as memory traces decay.
4. The sharing of attentional resources is made possible by the continuous and rapid shift from processing to maintenance.

On the basis of these four assumptions, when in working memory tasks the time necessary for processing is kept constant, any increase in the time required for the task increases the decay period of memory traces. This model is opposed to the Towse theory (Towse et al., 2005), in which the time required to process is varied. Differently, in the case of the TBRS model time is kept constant and more weight is given instead to the attentional shift and to maintenance of the information.

From a developmental perspective, the authors hypothesised that before seven years of age children do not use any attentional reactivation mechanisms. It has been found that in this age group the ability of working memory is not affected by the cognitive overload of concurrent tasks (Barrouillet, Gavens, Vergauwe, Gaillard & Camos, 2009). After seven years of age these mechanisms operate in the same way as in adults (Portrat, Camos & Barrouillet, 2008).

Despite their diversity, it must be emphasised that these models have contributed to a shift from the focus on a sigle aspect of working memory, that is its capacity, by proposing the need to better investigate its processes as a whole. At the same time they also pointed out the importance of these processes in an developmental perspective.

1.2. Executive functions and Central Executive

This chapter will describe the role, functions and processes undertaken by executive functions. The main purpose is to provide a literature background for the experimental chapter which investigates how the central executive systems contribute to combine information implicitly through the use of visuo-spatial bootstrapping (VSB) task (see chapter two). For this study, as it will described later, a dual-task paradigm was used in which digit sequences visually presented were administered under conditions of verbal working and central executive memory load.

1.2.1 Introduction

Executive function (EF) has been described as a construct that involves a mixture of high-level cognitive abilities (De Frias et al., 2006). Executive functions also are required for monitoring and modification of the behaviour in case of need or to adapt to new framework conditions. There are many processes that can be traced to the executive domain. These include abilities such: as attention shifting, inhibitory control, self-regulation, initiative and goal-directed behaviour, working memory, cognitive flexibility, use of feedback, strategic planning and problem solving (Barkley, 1997; Miyake, Friedman, Emerson, Witzki, Howerter, & Wager 2000; Zelazo & Müller, 2002). It needs to be recognised that, although goal-directed behaviour and response inhibition have been identified as important components of executive function (Weyandt, 2009), there is disagreement about this construct (Jurado & Rosselli, 2007).

The majority of research on executive functions comes from neuropsychological studies that focused on adults with damage on frontal lobe (Stuss & Benson, 1986). It has been observed from these studies that lesions in the prefrontal cortex are related with difficulties in the ability to inhibit behaviours, control impulses and plan (Luria, 1972). Despite this, the components that are most frequently investigated for information about executive functioning are: working memory (monitoring and updating the contents of working memory), cognitive flexibility (rapid and flexible movement between mental tasks) and inhibition (deliberate interruption of an automatic response). The executive domain does not end with the cognitive processes listed above but also calls into question the functions that play a key role in the regulation of emotions, motivation and behaviour (Garcia-Andres, Huertas-Martínez, Ardura, & Fernández-Alcaraz, 2010).

1.2.2 The Executive Functions in everyday life

Daily routine requires many steps to be taken in order to plan and execute different actions, such as: recalling from memory the commitments of the day, sequential planning of a number of tasks in order to achieve a goal, as well as taking account of various priorities, deadlines or emergencies. Executive functions are also crucial to reharse the goals of actions in order to assess whether goals have been achieved (Norman & Shallice, 1986). An additional task of executive functions is to analyse the causes of failure when goals are not achieved and to plan alternative actions. In cases when unexpected obstacles prevent the achievement of a certain goal, a significant amount of resources are needed to generate an alternative plan, inhibiting useless behaviours. Another potential cause for failure in achieving goals is the low reflectivity, or impulsivity in undertaking certain behaviours or actions (Zelazo, Craik & Booth, 2004).

In summary, the executive functions can be regarded as essential in determining the cognitive and motivational processes which are required to plan, execute and review actions in every day life.

1.2.3 The Central Executive

"The central executive is not an organ that might or might not exist, but a scientific concept. Part of its function is to separate the analysis of executive processes from the question of their anatomical location. Like other components of working memory, it is fractionable into subsystems" (Baddeley, 1998 b; pp. 423-426).

The conception of central executive originates from the first working memory model by Baddeley and Hitch (1974). Baddeley referred to executive control as the "heart of working memory" (Baddeley et al., 2010) and "the most important subsystem of the three-component working memory model and the one that presents the most difficult challenge" (Baddeley, 2007, pp. 117). The centrality of the executive control had also been recognised by Vandierendonck, De Vooght and Van der Goten (1998). Baddeley (1986) began to explore this concept as useful in describing the executive control, in a similar way to the Supervisory Attentional System (SAS) model proposed by Norman and Shallice (1986). Initially, its role, function and process were not specified and it was described as an all powerful homunculus that could manage all tasks that could not currently be explained by the model used initially (Baddeley, 2002). The concept of the central executive as an homunculus was then gradually abandoned. In turn specifying the roles to be played by the homunculus and identifying the tasks it needs to perform and the processes to achieve them (Baddeley, 2002).

The attentional control model from Norman and Shallice (1986) was borrowed to represent the central executive as it was the only model that proposed an action control mechanism of attention. The supervisory attentional system was thought to intervene when routine behaviours were not feasible in order to plan alternative actions. The supervisory attentional system model became a preliminary concept of the central executive. It started then to be analysed in all its separate functions (Baddeley, 1996).

In the past, the executive processes were strongly linked with the speculative *anatomical location* within the frontal lobes, as it was postulated by Shallice (1982). It has been observed that patients with 'frontal lobe syndrome' showed different kind of impairments in tasks that are believed to be dependent on the executive functions and caused by lesions to the frontal lobes (Shallice, 1988). However, Baddeley and Wilson (1998) pointed out that these processes cannot be considered unitary. They argued that the frontal lobes, being a large portion of the brain, cannot account for a unitary function. As opposite, the executive processes cannot be associated with only one area of the brain as they involve connections among different parts of the brain. As a consequence, it is possible to find patients with impairments in executive process without lesions in the frontal lobes. At the same time there are patients with frontal damage without clear evidence of executive deficits. For all these reasons, the dysexecutive syndrome instead of frontal lobe syndrome was proposed to be used in order to separate the anatomical location of executive functions.

One of the main methodologies used to investigate the processes and functions of the central executive is dual task performance (Baddeley et al., 1986), which allows to describe other executive processes such as attention switching, focused attention and the relation with long-term memory (Baddeley, 1996a). These functions have been explored, tested and divided into sub processes.

“The concept of a central executive represents just one of a number of possible approaches to the analysis of executive processes” (Baddeley, 1998; pp. 423-426). This concept has proved in several ways its importance for example separating the role of attentional control from phonological and visuo-spatial short-term memory systems facilitating their understanding. Moreover, through the concept of the dysexecutive syndrome has been explained the difference between the functional analysis of the executive processes and their anatomical location. The anatomical localisation can be used to investigate separable processes in order to obtain further evidence on executive functions (Baddeley, 1998 b). It can be postulated that the central executive has to be considered as a concept and not as a modular organ which has to be fractionated into subcomponents, similar to the other components of working memory. Using this approach, the complexity of executive processes can be understood identifying different sub processes involved. This concept was also applied to investigate cognitive deficits in patients with Alzheimer’s disease (AD). In the working memory domain, it has been observed that these kind of patients show an impartment of central executive (Morris & Baddeley, 1988; Spinnler, Della Sala, Bandera, & Baddeley, 1988). Using a dual-task performance it was possible to notice that patients with frontal lobe damage display a fractionation of executive processes (Baddeley & Della Sala, 1996a).

The central executive was considered as an attentional control system without storage capacity (Baddeley & Logie, 1999). The central executive was thought to integrate the two sub systems, verbal and visuo-spatial, linking them with long-term memory representations (Baddeley, 2002a).

Baddeley (1996) specifically focused on fractionating attentional control and studied the aspects involved in it. These aspects focus attention against distraction from irrelevant information, switching attention between two or more stimuli, dividing attention to perform two tasks at the same time and linking working memory and long-term memory (Baddeley, 1996). Different tasks and the methods of dissociation were used in order to investigate the separability of these functions and processes. A more relevant feature of working memory is the capacity to direct and focus attention (Baddeley, 2007). A limited capacity attentional system is long established in cognitive psychology (Miller, 1956; Broadbent, 1958; Neisser, 1967). However, under certain conditions, it can be possible to perform two complex tasks at the same time (Logie et al., 2004). One of the main groups of subjects used to explore the central executive functions are patients who suffer from

Alzheimer's disease (AD). As they showed distinct deficits in executive control along with a noticeable episodic memory, visual, and verbal immediate memory impairments (Spinnler et al., 1988). The capacity to divide attention was noted to be normal in younger and older people (Salthouse, Fristoe, McGuthry, & Hambrick, 1998), but vulnerable in patients with Alzheimer's disease (Baddeley et al., 1991; Logie et al., 2004). It has been suggested that "the capacity to divide attention is a candidate component of the central executive, while accepting that only time will tell how widely our results can be generalized" (Baddeley, 2007; pp. 136).

According to Baddeley et al. (2010), switching attention can be displayed in several ways according to the tasks to be performed and the availability of cognitive capacities. The investigation of switching attention initially started with the investigations by Jersild (1927) but received more interest years later (Allport, Styles & Hsieh, 1994; Los, 1996; Rogers & Monsell, 1995).

Using dual task methodology, it is possible to investigate whether executive components involve switching processes. Asking subjects to perform at the same time another switching task should result in a marked impaired performance. As a consequence, a task involving two different over learned sequences such as letters and numbers was developed. Participants were asked to recite them either as single sequences or in alternation (Baddeley et al., 1998), joining this with a random keyboard generation task. Subsequently, a similar task was developed using other two dissimilar over learned sequences, avoiding numbers in order to administer concurrent arithmetic. This time the task was to recite days of the week and months of the year either as single sequences (January, February, March, etc. or Monday, Tuesday, etc.) or mixed (Monday, January, Tuesday, etc.). This task involves both executive load and articulatory suppression and it has been used in study one of this thesis (see chapter two). In order to observe the cost of switching in the design used by Baddeley and colleagues (1998) arithmetic additions and subtractions, while subjects where performing both concurrent tasks in a single sequence or alternating days and months, were carried out. A clear switching effect demonstrating a distinct role of the central executive relateed to switching of attention for both concurrent verbal tasks was found. A further study with a less demanding task was carried out with a suppression task requiring to repeat the word 'the'. The same type of results with a less marked effect was obtained. This supports the hypothesis that the alternation design can involve processes beyond articulatory rehearsal (Baddeley, 2002).

To summarise, it can be claimed that the concept of central executive in the multi component working memory model by Baddeley has undergone numerous investigations and significant changes. The original model of working memory postulated by Baddeley and Hitch (1974) was composed by visuo-spatial and phonological temporary storage systems and a limited capacity executive component, which was initially hypothesised to be both storage system and attentionally based control. At this stage the central executive was not deeply explored and was considered as an all-powerful homunculus. Subsequently, the emphasis was focused on attention rather than storage (Baddeley, 1996; Baddeley & Logie, 1999) several limitations were encountered by the model.

1.2.4 Executive Functions across the lifespan

Concerning the development of executive functions, research seems to support the hypothesis according to which the executive domain is organised in different ways in different age groups. In particular, this could mean a progressive differentiation with years (for review, see Zelazo & Muller, 2002). Signs of differentiation of the various components executive emerge about 11 years and only stabilise at around 14/15 years (Lee, Bull, & Ho, 2013). “This growing ability to engage in deliberate, goal-directed thought and action, which depends on the increasing effectiveness of such processes as selective attention, working memory, and inhibitory control, is often studied under the rubric of executive function (EF).” (Zelazo et al., 2004; pp. 168).

First, the development of executive functions potentially covers a wide span of life: the precursors are already observable to a year of life. Pre-school and adolescence are characterised by rapid and significant progress and mature levels are achieved only in the third decade of life. Second, the development of executive functions is inextricably linked to structural and functional changes that affect the prefrontal cortex, along with cortical and sub cortical structures that act as neuroanatomical substrate. Finally, the development of executive functions has a hierarchical structure such that the first would appear the basic skills such as attentional control, working memory, and then the more complex skills and multifactorial (Senn, Espy, & Kaufman, 2004; Smidts, Jacobs, & Anderson, 2004).

Young children are characterised as impulsive, concrete and present-oriented (Inhelder & Piaget, 1964). As they grow they become able to represent different aspects of a problem, plan actions, act according to the plan and use information from mistakes (Zelazo et al. 2004).

Available information about the preschool period appears to show that between four and five years it is possible to observe the first signs of attentional control and a significant increase in the ability of inhibition, cognitive flexibility, working memory, decision making in the presence of punishments and rewards. During the school years some executive skills such as cognitive flexibility, reach maturity while others improve and strengthen gradually (inhibition, working memory, planning and theory of mind). The intensity of these changes increases significantly during adolescence: inhibition reaches adult level and there is a significant progress in load planning, working memory and emotional decision making. Between 20 and 29 years all executive domains record the achievement of the highest level of performance. A gradual decline during ageing has been observed (Mayr, Spieler, & Kliegl, 2001; McDowd & Shaw, 2000). This seems to suggest that the development of executive functions is like an inverted U-shaped curve (Dempster, 1992), as already demonstrated for other basic cognitive processes (Kail & Salthouse, 1994). There are few studies that have measured executive functions across the lifespan. One of the studies which analyse executive functions in subjects ranging in age from seven to eighty years was conducted by Comalli, Wapner and Werner (1962). They used the Stroop Colour-Word task, which is a classic measure of executive functions, discovering that the largest Stroop interference effect was found among seven-year-olds and in the oldest group of adults. Many other studies explored task switching across the lifespan finding contrasting results (Allport et al., 1994; Bedard, Martinussen, Ickowicz, & Tannock, 2004; Cepeda, Kramer, & Gonzalez de Sather, 2001; Williams, Ponesse, Schachar, Logan, & Tannock, 1999).

More recently, Cepeda and colleagues (2001) examined task switching in individuals from 7 to 82 years. Task switching arguably provides a measure of the participants' ability to adopt and change a problem-solving set, a key aspect of executive functions. In a series of trials, participants were shown either one or three numerical ones or threes (i.e., 1, 111, 3, or 333) and required to classify these stimuli differently depending on a cue (i.e. they were required either to indicate which numeral was displayed or to indicate how many numerals were displayed). A U-shaped function was obtained for switch costs the increase in reaction time (RT) on switch trials compared to non-switch trials. Cepeda and colleagues (2001) also found evidence that life span changes in switch costs could be attributed primarily to changes in the time needed to prepare for a new task, as opposed to changes in the decay rate of a previous task (Allport et al., 1994). In contrast to these studies, Williams and colleagues (1999) failed to find evidence of U-shaped age-related changes on another well-established measure of executive functions: stop-signal reaction time. In the stop-signal procedure, participants are presented with a series of stimuli and told to press one of two keys depending on whether an X or an O appeared. Unless they hear a tone (the stop signal), in which case they are to refrain from responding. These authors tested individuals ranging from six to eightyone years of age, and while they found improvement between the youngest group (six to eight years) and the middle childhood group (nine to twelve years), there was no evidence of an age-related increase in stop-signal RT during adulthood. Subsequent work, however, revealed U-shaped changes in stop-signal RT on a modified stop-signal task in which participants were required to stop when they heard one tone, but not when they heard another (Bedard et al., 2002).

1.2.5 Attentional control and individual differences

One of the first tasks proposed to measure the capacity of working memory is the Reading Span Task (Daneman & Carpenter, 1980). In this test, participants are asked to read lists of phrases and to judge the veracity of each sentence (the number of sentences ranges from two to six) and then, at the end of the presentation of each list, they have to remember the last word of every sentence in the correct order. Another classic test to measure the capacity of working memory is the Operation Span Task, proposed by Turner and Engle (1989). In this test participants must solve simple arithmetic tasks, reading aloud, and then remember the words that followed each operation. These tests must be distinguished from the tasks of short-term memory span which require low attentional control, since they provide for the maintenance of passive information. The processing required in the tests of working memory occupies the central executive, preventing a proper refresh (Heitz, Unsworth & Engle, 2005). Performance in tests that measure working memory are predictors of performance in a variety of complex cognitive tasks

(Daneman & Carpenter, 1980; Engle et al., 1991; Kyllonen & Christal, 1990). In particular, numerous studies reported that the executive component of working memory is responsible for the co-variation between working memory and complex cognition (Conway and Kane, 2001; Engle, 2001; 2002; Engle, Kane and Tuholski, 1999). In other words, as claimed by Kane and Engle (2003), the predictive utility of working memory tests lies in the attentional component of working memory, which regulates the activation of representations in memory, so keeping them in the attentional focus facing distractions and interference (Engle, 2002).

Engle and colleagues (1999) stated that the attentional control is the basis of individual and group differences. These differences in the ability of working memory reflect differences in attentional control, which allows the active maintenance of representations, action plans and targets. Especially in situations involving interference by representations activated automatically or distractions that may somehow deflect the attention from the representations currently needed (Engle, 2001, 2002; Engle et al., 1999; Engle et al., 1999a). For example, in the presence of interference, it is very likely to retrieve information and patterns of action that are irrelevant to the task that is taking place, resulting in the production of errors or delay in performance (Norman, 1981; Reason, 1990) .

Much experimental evidence confirms that individual differences in tasks of working memory capacity actually reflect the skills used in controlled attention to prevent distractions that come from environment or from interference of information stored in long-term memory. For example, Kane and Engle (2000) have analysed the relationship between the capacity of working memory and increased susceptibility to interference. The hypothesis was that if the attentional control is indispensable in situations of interference, then the ability to control the interference in conditions of divided attention should be damaged. The results show clearly that the performance of participants with reduced capacity working memory decreased, they were more sensitive to proactive interference than participants with high capacity working memory. However, the two groups did not differ in terms of dual task. The main difference in performance was that participants with high working memory capacity performed worse due to the increased cognitive load. In a different way, the performance of participants with low capacity working memory was not affected by the double task. The fact that the divided attention increases the proactive interference in participants with high capacity working memory, but does not affect the performance of participants with low capacity working memory highlights how the latter do not use the attentional control to prevent proactive interference in normal conditions. Although other studies have confirmed that people with high capacity working memory are those who have a good chance to have proactive interference (Lustig, May & Hasher, 2001; May, Hasher & Kane, 1999).

Differences between people with high and low capacity working memory also emerged in the Stroop task (Kane & Engle, 2003). In this task participants must call as quickly as possible the colour with which the words are written, regardless of their meaning. Some stimuli are congruent (eg. RED written in red) and other incongruent (eg. RED written in green). In the case of incongruent Stroop stimuli there is a strong tendency to provide a wrong answer, since there is a tendency to read the word, instead of stating its colour. A proper execution of this task requires a high attentional control. Kane and Engle (2003) varied the percentage of congruent Stroop stimuli in order to manipulate the easiness with which it is possible to keep the goal of the task (the higher the percentage of congruent Stroop stimuli, the harder it is to keep the objective). The results showed that participants with low working memory capacity reported a number of errors greater than that of subjects with high working memory capacity; only when the percentage of congruent Stroop stimuli was very high. These results highlight two important functions of working memory: 1) the maintenance of the objectives (for example, name the colour and do not read the word) and 2) the management of interference which inhibits preponderant responses (in the case of incongruent Stroop stimuli) (Heitz, et al, 2005). Even using other paradigms, such as dichotic listening (Conway et al., 2001) and anti saccade test (Kane, Bleckley, Conway & Engle, 2001), it is clear that the tasks require a high attentional control to actively maintain information, to inhibit interfering or distracting information, or block overwhelming answers. This allows for the ability to distinguish between subjects with high and low working memory capacity.

1.2.6 Executive functions: unitary or fractional

Executive functions refer to the processes that control and regulate our thoughts and our actions. Hedden and Gabrieli (2004) define the executive processes as cognitive mechanisms which organise and manipulate information in working memory and switch between multiple tasks and sources of information. Research on executive functions has its roots in the neuropsychological studies of patients with injuries to the frontal lobes, which have a specific difficulty in voluntary control of behaviour without showing any problem in performing regular action sequences. These patients typically perform normally in specific cognitive tasks and in IQ tests, but their performance in a number of executive tasks is extremely impaired (Damasio, 1994). Executive functions are associated with the frontal lobes, and especially the prefrontal areas (Smith & Jonides, 1999). Ladavas and Berti (1999) listed a number of reasons in support of this hypothesis. First, this cortical area is much more developed than the other regions. It occupies about a third of the entire brain. In addition, it is connected to all the functional systems of the brain, as it is very rich in connections both afferent and efferent. Finally, it is one of the phylogenetically most recent developed structures of the brain, and among those that progress more slowly from the ontogenetic point of view.

A review of neuropsychological studies in the literature identified the main issues under debate about the executive functions: organisation of the executive domain, developmental trajectories of executive functions, impairments of executive functioning and the impact in the daily life of a correct or compromised executive functioning (see Marzocchi & Valagussa, 2011; Cantagallo, Jostling & Antonucci, 2010).

One of the critical issues in the study of executive functions is the definition of the ways in which they are organised.

Duncan, Johnson, Swales and Freer (1997) have raised a controversial issue based on Teuber (1972) that has characterised the study of executive functions in recent years: do the different functions which are generally attributed to the central executive (or Supervisory Attentional System) or to the frontal lobes reflect the activity of the same underlying mechanism or ability?

From a historical perspective, it can be observed that the concept of executive functions has moved from unitary models to fractional models, from integrated models to sequential ones. In the *unitary models* executive functions are conceptualised as a unitary and general domain that can manifest itself in peculiar ways according to the requests and demands of the context. Examples are the model of the Supervisor Attentional System (SAS; Shallice & Norman, 1986) and the original model of working memory by Baddeley and Hitch (1974). The SAS and the central executive would have the duty to exercise strategic control on cognitive processes, selectively displacing the attention of a process and to organise effectively subroutine at levels hierarchically lower. In the initial formulation of the working memory model by Baddeley (Baddeley & Hitch, 1974) the central executive was described as central and unified, not assuming any subcomponent inside. Even recent theories have suggested the existence of a common, or at least a unifying mechanism that characterises the nature of the deficiency in patients with damage to the frontal lobe (Duncan et al., 1997; Engle et al., 1999). However, research conducted in the following years has shown that unitary models are too simplistic and provided directions for the hypothesis that the executive domain is composed of different components.

Currently, the hypothesis of *non-unitary* executive functions has received growing attention. In this model, executive functions are described as a set of voluntary processes, which can be either independent or interactive. Baddeley (1996), in a subsequent reformulation of his model, suggested that the executive component of working memory can be divided into subcomponents. The initial idea of a central and unitary system has been modified into a almost-modular and distributed system.

Subsequently there were other models that predict a split domain of executive functions in distinct components. The various models differ in the number and range of processes identified and for the type of relationships between. Then, Levin and Welsh (1991) have proposed two overlapping models that include: rapid response, generation of impulse control and planning. Pennington and Ozonoff (1996) have conducted a review of the work of cognitive psychology and neuropsychology that led them to circumscribe the roles of executive functions to five most recurrent functions, such as inhibition, planning, working memory, cognitive flexibility and verbal fluency. Barkley (1997) proposed a model in which the crucial factor is the behavioural inhibition that determines the development and operation of many subsidiary mechanisms: working memory, internalised language, regulation of emotion, motivation and activation and analysis of the events. Moreover, Miyake and colleagues (2000) proposed a model that identifies three executive processes: cognitive flexibility, inhibition and working memory. An integration between the cognitive processes of the executive functions is observed in the publication of Anderson and colleagues (2002). The authors, in line with the neuropsychological models previously presented, identified a series of processes in which the executive domain can be subdivided, but they speculated integration between the different executive functions. The executive processes (cognitive flexibility, goal setting, attentional control and information processing) function as a control, task-dependent single system. Finally, the sequential models suggest that different components are described in the executive function of how they contribute to the resolution of problems or to overcome a complex task. Examples are the model of Zelazo, Carter, Resnick and Frye (1997) and the model of Burgess (2000). Zelazo and collaborators (1997) describe how the different executive processes operate in an integrated way in order to solve a problem and/or achieve goals. The model by Zelazo indicates four stages which are temporally and functionally distinct: representation of the problem, planning, execution and evaluation of the work. Burgess instead describes executive functions as sequential processes that come into play in the performance of a task: learning the rules of the task, planning steps to be performed, execution of the task, checking the consistency between planning and execution, and finally re-enactment of the performance.

Some evidence in the direction of fractional models comes from *neuropsychological studies* that show the presence of dissociation in performance to different executive tasks. For example, some patients with frontal lesions show difficulties in the Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Talley, Kay, & Curtiss, 1993; Monchi, Petrides, Petre, Worsley & Dagher, 2001), but not in the test of the Tower of Hanoi (TOH; Welsh & Huizinga, 2001). On the contrary, others show the opposite pattern (Godefroy, Cabaret, Petit-Chenal, Pruvo & Rousseaux, 1999; Shallice, 1988).

In addition, neuroimaging studies have shown a clear dissociation between the various processes. In this regard, Smith and Jonides (1999) took into account studies using techniques such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) stressing how the various executive tasks activate different areas of the frontal cortex. Even studies on individual differences turned up evidence in support of the fractional nature of executive functions. In these studies, with different populations, a battery of tests widely used to investigate the executive processes was administered to the participants. Apart from the details of the results, which obviously vary between different studies, correlational analyses showed that the interrelationships between the various tasks are extremely low or even insignificant (Duncan et al., 1997; Levin, Fletcher, Kufera, Harward, Lilly, Mendelsohn, Bruce & Eisenberg, 1996; Lowe & Rabbitt, 1997). However, Baddeley and colleagues (1997) reported significant limitations of approaches based on factor or correlational analysis, when they attempt to bring evidence to support the non-unitary executive functions. First, it is unclear whether the lack of correlation between the executive functions (common result to the various studies mentioned above) actually reflects the fractional nature of executive functions (Miyake & Shah, 1999). This is most likely due to the non-executive processing demands (for example language processing vs. visuospatial processing), which are different from task to task, and might have masked the presence of a common factor underlying the tasks in question. The foregoing is linked to the problem of the role of executive functions as they work on the other cognitive processes, which are, therefore, inherently mixed to them. Therefore, due to the low correlations between the performances in executive tests and other neuropsychological assessments in patients performing these kind of tests, caution should be used in interpreting this as evidence in favour of non-unitary executive functioning. Further complications are also added by the low internal reliability and test-retest of the tests in question (Denckla, 1996). The reason is still unclear. Probably when people perform these tasks, they adopt different strategies on different occasions. Also, since the involvement of the control processes is more massive when the task is new, the effectiveness of the measures that investigate these processes is reduced as a result of repeated administrations. Moreover, it is known that measures with low reliability often show low correlations with other measures. Finally, the low correlations between the executive tests found in various studies would be more attributable to their lack of reliability that a true independency of the executive functions.

A further problem is the construct validity of complex executive tasks, such as Wisconsin Card Sorting Test and Tower of Hanoi. Although these tests are widely considered measures to investigate the processes of control, their construct validity have not yet been established (Phillips, 1997). There is a lack of rigorous theoretical analysis and empirical evidence to establish what these tests are really measuring. It frequently happens that many of the best known executive tasks are validated for the simple reason of being susceptible to frontal injury. The lack of clarity around these executive tasks is reflected in the proliferation of terms and concepts used to specify the demands of processing of several tasks (Miyake et al., 2000). For example, different researchers have considered the Wisconsin Card Sorting Test a measure of the processes of inhibition, the mental flexibility, the problem solving, the processes of categorisation, and so forth. This leads to serious difficulties in interpreting which construct of executive functions is actually represented by different factors which are obtained through studies of factor analysis. As noted by Miyake and colleagues (2000), often the interpretations attributed to these factors are rather arbitrary and post-hoc.

To sum up, all data reported here highlight the ineffectiveness of the factor analysis or correlational studies to provide useful data to the formulation of theories and models on the organisation of executive functions and their role in cognition. Nevertheless, results reported in different areas of research confirm the hypothesis that executive functions can be broken down into distinct functional and anatomical characteristics (Baddeley, 1996; Shallice & Burgess, 1993).

1.2.7 A taxonomy of executive functions

Miyake and colleagues (2000) emphasised the need for a new approach to the study of these important cognitive processes, by examining three executive functions using the methods of data analysis that extract the latent variables underlying the cognitive measures. Despite the lack of consensus on a definitive taxonomy relating to executive functions, the study of Miyake and colleagues (2000) focused on the three executive functions most frequently postulated in the literature: 1) the shifting between tasks or mental set; 2) the updating and monitoring of the representations present in working memory; and 3) the inhibition of predominant or inappropriate feedback (Baddeley, 1996; Smith & Jonides, 1999).

The reasons why Miyake and colleagues (2000) have focused on these three executive functions are multiple: a) they are relatively circumscribed and then more precisely defined from the operational point of view. Moreover, these functions are in a lower hierarchical level than other executive functions such as planning. b) There are various relatively simple tests, well known and studied, that are considered reliable measures of these functions; c) most likely the three target functions are required in the performance of more complex executive tasks (for example the Wisconsin Card Sorting Test would be a measure of shifting and inhibition). The understanding of these three basic functions is essential for a correct specification of what traditional executive tests really measure.

It is useful at this point to briefly describe the three functions before analysing the results of the study of Miyake and colleagues (2000). Shifting between tasks or mental set-*Shifting*. This feature concerns the ability to move the attention to a particular task or mental set to another. This ability, according to the models of attentional control, is an important aspect of executive control (Norman & Shallice, 1986). It is essential to explain the difficulties faced by both patients with frontal damage and participants in laboratory tests performing tests that require switch from one task to another (Monsell, 1996). The process of shifting can be interpreted as the undocking from one irrelevant task to the next more relevant and active. A growing number of neuropsychological and neurophysiological evidence suggests the frontal lobes, in particular the anterior cingulate, are involved, along with other regions of the brain (occipital and parietal areas) in shifting between set and mental tasks. Furthermore, it has been argued that the perseveration and the several repetitions of the same answer even when clearly this is no longer appropriate characterise the performance of patients with frontal damage. This may depend on the difficulty in changing mental set (Stuss & Benson, 1986).

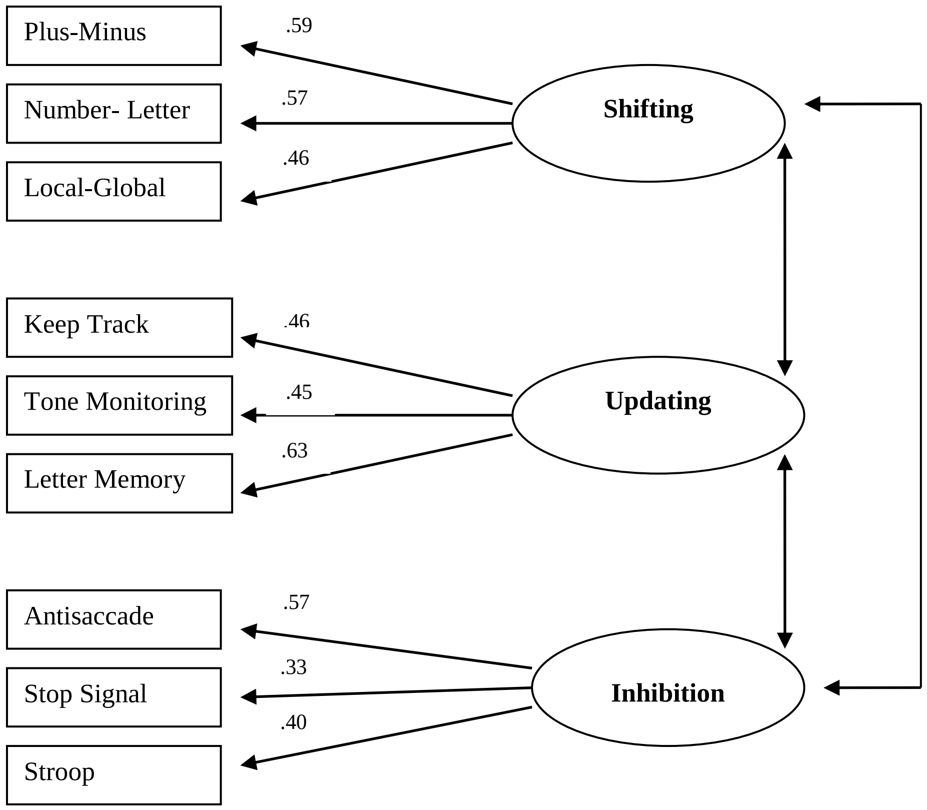
Updating and monitoring the representations present in working memory- *Updating*. The second target function is closely linked to the notion of working memory. The function of updating requires both the monitoring and the encoding of the information to establish the relevance for the task in progress and the replacement of information present in working memory (Morris & Jones, 1990). It must be emphasised that the upgrade process allows not only to keep the relevant information for a given task inside the working memory, but also to manipulate them.

Inhibition of dominant answer - *Inhibition*. The last executive function taken into consideration is the ability to inhibit, or rather, deliberately suppress prepotent and automatic responses, when these are inappropriate. This function is linked to the frontal lobes and is involved in the prototypical Stroop task, in which it is necessary to inhibit the tendency to produce an automatic response, such as reading the word that indicates a colour.

The results of this study (Miyake et al., 2000) are extremely interesting, as they suggest that the three executive functions are a clearly distinguishable target, although not entirely independent of each other, as they seem to share some common underlying factors. In other words, the executive function of shifting, updating and inhibition are separable constructs, but at the same time, moderately correlated, highlighting both the unitary and fractional nature of the executive functions (Figure 6). These results help to unravel the controversy unity versus diversity, which in recent years has driven the debate on the executive functions. Noting that a simple dichotomy is not enough to explain this phenomenon, but it is necessary to consider both aspects to get a more precise executive functions. Miyake and colleagues (2000) have attempted to interpret what is the nature of the unitary executive functions by proposing two possible explanations. In the first, it is assumed that the tasks used in the study, despite of specific functions investigated, may share some common task requirements, such as maintaining the objectives and context information inside working memory. Consequently, the ability to actively keep the information about the objectives of the task in working memory. Along with other information relevant to the task, during the process of active elaboration, would be the basis of the unity between the three executive functions. Another possible explanation supposes that all three executive functions, to operate adequately, involve some form of inhibitory process. For example, the function of updating would require the bypass of irrelevant information and suppress those no longer relevant. In the same way, the function of shifting to be able to switch to a new mental set, would require to suppress or disable the previous mental set. In addition, this type of inhibition, which would consist of the suppression of information or irrelevant mental sets, could be related with the process of deliberate and controlled inhibition of predominant answers to the function of inhibition.

Another important result that emerges from the study of Miyake and colleagues (2000) shows that the complex tests of executive functions, frequently used in cognitive and neuropsychological studies are not completely homogeneous. As the different executive functions operate differently during such tasks. For example, the authors found that set shifting plays an important role in the Wisconsin Card Sorting Test (Heaton, et al., 1993), and inhibition in the test of Tower of Hanoi (Welsh & Huizinga, 2001). Instead, the performance in the Tower of Hanoi Task depend both from inhibition and updating.

Figure 6. The structural equation model to three factors identified by Miyake and colleagues (2000).



Finally, Miyake et al. (2000) claim that the three executive functions analysed in their research are definitely not the only executive functions. A pragmatic selection was made, which actually allowed to take a first step toward understanding the nature of executive functions. However, there are still many questions about other important basic function and the relationship between these and the more complex executive functions, such as planning. In this regard it is interesting to quote the study of Fisk and Sharp (2004) that in an attempt to confirm the results of Miyake and colleagues (2000) have extended the sample by administering to subjects aged from 20 to 81 years old a series of different executive tests. Some of these tests are the same used by Miyake and colleagues (2000); in addition, Fisk and Sharp (2004) have also administered a test of verbal fluency, a test of random generation of letters and the task of spatial sequences of Brooks (1968). In general, the results obtained in this study are consistent with those of Miyake and colleagues (2000) and demonstrate that the differences between the functions of shifting, updating and inhibition can be generalised also to a larger sample and heterogeneous group of subjects. An interesting result concerns measures to the tasks of verbal fluency and random generation of letters. This study shows that verbal fluency appears to use a fourth executive process which is connected to efficiency to accessing long-term memory. In addition, the measures of generating random letters appear to be associated to this component, rather than the function of updating, as Miyake and colleagues (2000) found. Probably, the task of generating random letters, unlike the task of generating random numbers (used by Miyake et al., 2000). Besides using the component of inhibition, would also involve a further executive process tied to efficiency in access to information in long-term memory.

1.2.8 Clinical aspects of Executive Functions

There are many clinical situations where there are difficulties in planning, organisation, behavioural control or flexibility in adapting to new situations. Generally in children and adolescents who have problems with one or more executive domains it is possible to observe the following behaviours: inability to learn from experience, distractibility and clumsiness, difficulty performing multiple tasks simultaneously, carelessness and disorganisation, difficulty controlling automatic responses, marked uncertainty in the academic performance, lack of awareness of others' feelings and social conventions, tireless and talkative or under activation, difficulties in regulating emotions, impatience and poor tolerance to frustration, difficulty in moving from one activity to another, difficulty to establish priorities and meet deadlines, losing track of time, chronic slowness, procrastination and/or difficulties to undertake new tasks (Best & Miller, 2010). From a clinical perspective, it can be seen that special attention and investigation has been paid to the executive functioning of children and adolescents with the following clinical conditions: attention deficit disorder and hyperactivity disorder (ADHD), Specific Learning Disorder (SpLDs) Pervasive Developmental Disorders (PDD), Tourette syndrome (Hosenbocus & Chahal, 2012). A deficit charged to the inhibitory domain would seem to characterise all the clinical conditions; it is possible to observe: 1) impairment of working memory and alertness in children and adolescents with ADHD, 2) problems affecting the cognitive flexibility, planning and memory work in children and adolescents with Pervasive Developmental Disorders, 3) deficit against fluency and cognitive flexibility in children and adolescents born preterm, 4) specific impairments during the performance in tests aimed to assess working memory in children and adolescents diagnosed with Specific Learning Disorder.

The considerable increase of interest in the executive functions of recent decades is also tied to the pivotal role they have in everyday life and the ability to perform, on the basis of individual differences in executive functioning, inferences about specific developmental outcome. Regarding the everyday habits, individuals use the executive functions to learn new actions, to plan and make decisions, to correct their mistakes, to implement difficult or dangerous behaviours, to perform behaviours that require constant monitoring which are not automatic and consolidated. Regarding life outcomes, it is interesting to note that a good executive functioning potentially binds to higher reading, writing, and language skills, better educational outcomes in the various levels of education, higher social skills at different stages of life, better quality of life and economic status and fewer legal problems in adulthood.

1.2.9 Conclusions

Executive functions are an essential cognitive process as they allow to put in place flexible and appropriate behaviour according to the circumstances. Research on executive functions has its roots in the neuropsychological studies of patients with frontal damage, where there is a specific difficulty in voluntary control of behaviour, without showing any problem in execution of sequences of habitual actions (Damasio, 1994). In fact, a credible hypothesis associates executive functions, typically considered human function, to the frontal lobes, and especially the prefrontal areas (Jonides & Smith, 1999).

One of the most important cognitive structures often associated with executive functions is the central executive which is able to control and coordinate the cognitive processes (Baddeley, 1986). Baddeley (1990) considered the central executive more as a control system of behaviour than a storage component. This system is similar to the supervisor attentional system of working memory proposed by Norman and Shallice (1986).

The long debate about fractional unitary executive functioning seems to be resolved following the evidence reported by Miyake and colleagues (2000). The executive functions of shifting, updating and inhibition are clearly distinguishable, even if not completely independent of each other. Even though they seem to share some common underlying factors. Miyake and colleagues (2000) concluded that a simple dichotomy is not enough to explain this phenomenon, but it is necessary to consider both aspects of unity and diversity to have a more precise executive functions.

1.3. Binding

In this section, different types of binding have been reviewed, with particular concern in binding across domains. The last part of this section was dedicated to a recent line of investigation on working memory binding which concerns a series of studies on visuo-spatial bootstrapping effect. The experimental programme (see chapters two, three and five) is designed to understand the role of central executive in the bootstrapping effect and how this effect affects working memory across the lifespan and in patients who start to show memory difficulties, such as patients with Mild Cognitive Impairment.

1.3.1 Introduction

Binding can be defined as a set of processes through which elements of the experience are bound together to create coherent representations in memory (Allen, 2015). Information from different feautures and modalities are linkeded together creating a meaningful organization of our experience, instead of confused stimuli. Binding is a cognitive function which ensures representation of the relation and conjuction of multiple features into unitifized objects (Moses & Ryan, 2006).

The mechanism of binding features into integrated representations has been suggested to be one of the prime functions of consciousness. This process provides the further benefit of serving as a general workspace that promotes complex cognitive processes such as reasoning and comprehension (Baars, 1997, 2002). A similar role has been hypothesised by Baddeley (2000, 2007), who attributes it to the operations of the episodic buffer. This is the most recently added element of the multi-component model of working memory initially proposed by Baddeley and Hitch (1974). The episodic buffer (EB) was more recently added to the model (Baddeley, 2000). It was thought to serve as a temporary storage and as a component that integrates information from the other storage systems and long-term memory into a unitary representation, which can be then accessed through conscious awareness (Baddeley et al., 2011; Logie, 2011; Repovs & Baddeley, 2006). Repovs and Baddeley (2006) postulated that the features held by the episodic buffer are stored in unitary representation or object. This interpretation of integrated object storage is similar to the domain-general focus of attention postulated by Cowan (2001, 2005).

The difference between the two models is that in the latter model chunks rather than features are used to measure storage capacity (Morey, 2009). It can be noted that storage of objects with cross-domain features can be possible at object or features level within the multiple component working memory model by Baddeley. Cross-domain representations can also be maintained in a general working memory store in association with specific domain (Morey, 2009).

Several processes can be explained through the episodic buffer. Specifically, it accounts for how stimuli are bound together to create coherent representations in memory with multidimensional features and specific meaning. These elements are usually linked to context and can potentially influence further actions (Allen, 2015). This is true both for visual and verbal stimuli. Objects in the visual domain comprise of several distinct characteristics such as colour, shape and size, as well as linguistic elements which are integrated in a unitary and coherent representation rather than remaining isolated pieces of information. In general, our knowledge of the world is organised to form significant and coherent experiences rather than being a chaotic number of stimuli without a specific connotation. All these processes involve what has been defined as “binding”, which integrates information from different modalities and sources in memory. There are several forms of binding according to different contexts and stimuli.

A number of authors have investigated the process of binding since the proposal of the episodic buffer. Baddeley and colleagues (2012) assume that the episodic buffer has a central role in providing a multidimensional medium, allowing to bind together chunks or features from different sources, both for visual and verbal binding. It would not appear that the process of binding requires the active manipulation of information within the episodic buffer, as in the original proposal of the component was postulated. Episodic buffer is now considered an essentially passive system, even if there are more complex forms of binding which may not be passive (Baddeley et al., 2011). For instance, it has been noted that binding of different features does not require a greater involvement of attention than storing features taken alone. Specifically, studies have shown that binding of colour and shape is automatic (Allen et al., 2006) when the integration is performed based both on visual and verbal information (Allen et al., 2009). At the same time, binding can also take place incidentally, for instance when spatial information is coded incidentally with visual information (Corder & Galera, 2009; Jiang, Olson & Chun, 2000; Olson & Marchuetz, 2005). Another relevant characteristic attributed to episodic buffer is that it allows executive processes to carry out further manipulation to those explained above. This means that other forms of binding could be investigated, such as binding of objects into complex scenes or phrases into integrated sentences (Baddeley et al., 2012).

It is important to note that other terms are used interchangeably when referring to binding, such as chunking and grouping. This different terminology can be useful to differentiate specific functions of binding. For instance, chunking can be used to refer to a strategic methodology to link information together based on semantic or perceptual meaning (Miller, 1956).

Binding is a relatively new topic in the context of working memory and long-term memory with contributions from different disciplines such as cognitive psychology and neuroscience. It is considered a fundamental cognitive function which integrates in a singular representation multiple features that constitute complex stimuli or rich experience (Treisman, 2006; Zimmer, Mecklinger, & Lindenberger, 2006). Specifically, the role of binding in memory is to create meaningful representations linking items such as names and faces, and connecting features into objects, integrating for example shapes and colours (Della Sala, Parra, Fabi, Luzzi, & Abrahams, 2012).

The exploration of binding also implies the understanding of how different brain areas are activated in processing sensory information linked with more active manipulation in working memory and subsequently integrated in long-term memory. This area of investigation includes studies on how the process of binding is achieved through the role of memory and attention. Other studies have examined how binding changes across the lifespan and in patients with cognitive impairments, specifically with memory difficulties. Research has demonstrated that both relational and conjunctive binding functions work both in long-term memory (Moses & Ryan, 2006) and in short-term memory (Piekema, Kessels, Mars, Petersson, & Fernandez, 2006; Piekema, Kessels, Rijpkema, & Fernandez, 2009; Piekema, Rijpkema, Fernandez, & Kessels, 2010). Relational or extrinsic forms of binding refers to the contextual features, while conjunctive or intrinsic is concerned with the characteristics of the object itself (Ecker, Maybery, & Zimmer, 2012). Both are affected by Alzheimer's disease (AD), although in different ways (O'Connell et al., 2004; Parra, Abrahams, Logie, & Della Sala, 2009; Parra, Abrahams, Logie, Mendez, Lopera, & Della Sala, 2010; Parra, Della Sala, Abrahams, Logie, Mendez, & Lopera, 2011). Conjunctive binding seems to be more affected by Alzheimer's disease when compared with other age-related conditions and healthy ageing (Brockmole, Parra, Della Sala, & Logie, 2008; Brown & Brockmole, 2010; Parra, Abrahams, Logie, & Della Sala, 2010).

Despite several working memory models focusing on examining the different components and processes of this system, the processes of binding received attention only recently. A substantial amount of studies have investigated binding specifically in relation to working memory, which is the system involved in temporarily maintaining and manipulating information. It has to be noted that while binding was initially considered as a unitary function, Baddeley and colleagues (2012) has suggested that there are several kinds of binding, such as perceptual or linguistic. Binding can also vary according to the involvement of working memory or long term-memory, and it can be temporary or durable, binding new information to its context (Baddeley et al., 2012). This recent interest in the process of binding could shed further light on the limited capacity of working memory and the nature and processes of representational storage (Allen, 2015).

1.3.2 Visuo-spatial Binding

"Visual working memory (WM) is a temporary buffer that can maintain a limited set of items in an "online" state" (Luria & Vogel, 2011; pp. 1632-1639). Visuo-spatial binding is one of the areas of visual perception most investigated with the aim to determine how neural codes are combined to enable perception of objects in the environment (Treisman & Gelade, 1980). Similarly, visuo-spatial binding received a large amount of attention in working memory investigating how visual and spatial features are combined together. For instance, linking colour, shape, location and orientation. Several studies used the same paradigm composed by arrays of visual stimuli requiring participants to recognise them through the binding processes (Allen, 2015). The role of attention in these tasks had always received particular interest as it was considered a necessary component for the episodic buffer in binding information. However, in the most recent experiments on visual spatial binding (Baddeley et al., 2011), according to the multi component model of working memory (Baddeley, 2000), it has been demonstrated that the episodic buffer does not require attention in binding (Baddeley et al., 2011). No difference was observed between tasks which require to decide whether a colour and shape association had been shown in a previous display and others that require to decide whether a test shape or colour had been presented in an attentional manipulation concurrent task (Allen et al., 2006). This has led to the conclusion that binding can occur automatically without the involvement of attention for simple unitised objects (Baddeley et al., 2011).

Another area of investigation in visual working memory concerns the nature of its representative format when colour and shapes are linked with creating objects. A well-known paradigm used to study visual working memory is the change detection paradigm (Luck & Vogel, 1997). This paradigm is composed by presentation of a memory array such as set of objects, followed by a short interval and then a test array. The task aims to indicate whether the test array is similar or different to the remembered memory array. According to the investigation conducted by Luck and Vogel (1997), it has been argued that visual working memory representations have a limited capacity by object rather than number of features (Vogel, Woodman, & Luck, 2001). Luck and Vogel (1997) observed that objects, and not features, are the building blocks of visual working memory. Moreover, they (Luck & Vogel, 1997) demonstrated that performance was identical for objects that had only a single feature in comparison to objects that had multiple features, such as colour and orientation. The authors found that it is possible to retain only four pieces of information (colours or orientations) in visual working memory at one time. At the same time, colour and the orientation of four objects can be retained together, demonstrating that visual working memory combines objects rather than individual features (Luck & Vogel, 1997). In this way, they claimed that objects composed by four features can be retained similarly to single-feature objects. Because of this capacity of visual working memory is then considered in terms of integrated objects rather than individual features (Luck & Vogel, 1997).

An opposite position is raised up by Wheeler and Treisman (2002) who claimed that visual working memory is composed by separate feature stores. According to this last point of view, attention is particularly important in the process of binding, because the capacity of working memory is defined both by the independent capacity of simple feature stores and by attention which combine this distributed information into unified objects (Wheeler & Treisman, 2002).

Using a change-detection paradigm with objects defined by colour with location or shape, Wheeler and Treisman (2002) found that features from the same dimension compete for capacity while features from different dimensions may be stored in parallel. In accordance with this perspective, it has been observed that binding is fragile to interference from other stimuli presented sequentially (Allen et al., 2006). Binding results fragile when there are other perceived interfering stimuli in the environment, even if they are not elaborated by working memory processes (Ueno et al., 2011). Moreover, it has been observed that binding in memory can cause a partial loss of features of the original characteristics of an object. For instance it is possible to remember the colour of an object, but not its form (Cowan, Blume, & Saults, 2013). From this perspective, it seems that multiple attributes compete for attention. In order to retain binding between attributes is necessary to retain the attributes themselves. The number of attributes contributes to a restricted number of objects processed in working memory. However, the set of attributes can be dependent on the focus of attention (Cowan et al., 2013).

Another line of investigation on visuo-spatial binding concerns the process of linking together attributes that are not part of the same object. It has been demonstrated that it is easier to remember visual characteristics of a stimulus concerning the same object or within the same space rather than characteristics that are spatially distinct (Allen, 2015).
Visuo-spatial binding has been subdivided in two different processes such as intrinsic and extrinsic (Ecker et al., 2012). Intrinsic binding belongs to the characteristics of the object itself, such as colour and shape, while the extrinsic refers to the contextual features, like the colour and shape of an object close to the target. According to this division, it has been noticed that intrinsic binding can be automatic, rather than the extrinsic needs further cognitive resources. Eckter and colleagues (2012) claimed that extrinsic and contextual binding necessitates of an active and strategic encoding. These observations are linked with working memory as a system which actively integrates information from separate components of a setting. This form of binding seems to be related with individual differences in the capacity of working memory as well as fluid intelligence and reasoning (Oberaurer, Süß, Wilhelm & Wittmann, 2008).

1.3.3 Verbal Binding

Binding during verbal tasks could operate in a hierarchical structure. This may work binding components and elements such as syllables and phonemes and their position (Baddeley et al., 2009). On a more complex level, it involves words for the production of meaningful sentences and the creation of concepts for mental models and representations (Allen, 2015). It is well- known that it is easier to remember meaningful sequences rather than random list of words indicating that this can be an example on how binding can operate in verbal domain. This has been demonstrated in a study conducted by Baddeley and colleagues (2009) which showed that recall for sentences over lists of words was not reduced by demanding concurrent tasks despite of a considerable effect on performance. Moreover, binding between elements of a sentence seems to be automatic without the contribution of attention. This process involves a direct access to linguistic knowledge stored in long-term memory. This mechanism seems to be linked with the episodic buffer in working memory which stores bound meaningful segments. The same results have been found in binding across sentences presented in the context of a meaningful narrative rather than presented in a random and trivial order (Jefferies, Lambon, Ralph & Baddeley, 2004). Attention seems to be relevant only in the case of new constructed schematic narrative segments while there is no need of it in binding meaningful sentences.

1.3.4 Binding and Long-Term Memory

One of the intriguing areas under investigation of binding process concerns the relation between long-term memory and binding (Baddeley, 2000; Baddeley et al, 2009). Studies have been developed in order to understand how working memory and long-term memory interact creating representations over the short term through binding. It has been noted that processes of binding and working memory, and long-term memory representations are reciprocally supportive (Allen, 2015). Studies have been carried out on both visuo-spatial and verbal binding (Baddeley et al., 2011; Logie et al., 2009). Regarding verbal binding, it has been noted that both new binding working memory and familiar conjunctions in long-term memory do not require the involvement of attention as they can occur automatically (Hommel & Colzato, 2009). Similar results have been obtained in tasks with unrelated words or with non-words pairs, noticing that divided attention did not affect the performance on that task (Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003). These processes are different according to the form of binding and the stimuli used in the tasks (Allen, 2015).

Another interesting position on the distinction between working memory and long-term memory binding arrives from studies on intrinsic and extrinsic forms of binding (Ecker et al., 2012) which are similar in some aspects to the distinction between conjunctive and relational integration (Moses & Ryan, 2006). As it was already described above, intrinsic binding refers to the characteristics of the object itself, while the extrinsic indicates the contextual features. According to these theorisations, it can be hypothesised that long-term memory requires attentional control in tasks involving extrinsic binding in the same way of working memory. In this context the performance of the two kind of memory seems to share analogous pattern of responses (Ecker et al., 2012). However, further research needs to be conducted in order to clarify the association formation in long-term memory and binding.

1.3.5 Executive Load

Allen and colleagues (2006) investigated the role of the central executive in binding tasks. This research program tested the function of central executive while it was blocked. This study involved the investigation of two domains, binding of visuo-spatial features creating objects. In the visuo-spatial domain they assessed the recognition of either isolated features (shapes or colours) and association of these features into integrated objects through probe recognition tasks. At the same time participants were asked to perform a secondary task, such as counting backward in threes during the encoding, which should have loaded the central executive. Blocking the central executive resulted in a substantial decrease in recall performance, both in binding and in the single feature conditions. This led to the conclusion that binding features into objects and encoding individual features involve the same executive resources (Allen et al., 2006). In a similar way, Karlsen and colleagues (2010) found that the recruitment of central executive resources was the same for both binding of spatially or temporally separated features and for the encoding of bound characteristics. This finding can also be extended for other modalities, such as visually and auditorily (Allen, et al, 2009). Similarly, other studies obtained the same type of results, showing that attention is not necessary in the maintenance of feature bindings in visual short-term memory (Delvenne, Cleermans & Laloyaux, 2010; Johnson, Hollingworth & Luck, 2008). On the contrary, there are some authors that do not support the automacity of binding visuo-spatial features (Olson & Jiang, 2002; Wheeler & Treisman, 2002). However, Baddeley et al. (2011) concluded that binding in the perceptual system does not require the involvement of the central executive.

The role of executive load on the recall and recognition of visual objects has been observed to have a considerable negative impact in studies that have used simultaneous presented arrays (Allen et al., 2006; Dell'Acqua & Jolicoueur, 2000). Allen and colleagues (2014) investigated the effect of executive load on the recall of sequences of colours, shapes and bound objects hypothesizing that the most recently presented item could be automatically processed without additional executive support. Executive resources may be fundamental in order to enable earlier information to be accessible and be preserved from potential interference. In the study conducted by Allen and colleagues (2014) the role of executive load was investigated through three experiments administering demanding concurrent tasks such as backward counting with serial presentation. They found that bound representations are sensitive to be overwritten by other subsequent stimuli and they need an investment of executive control in order to maintain a sequence of binding information. This is consistent with the finding by Wheeler and Treisman (2002) who underlined the involvement of attention. Allen and colleagues (2014) observed that an increased executive load does affects memory for binding, just as it affects memory for features. It just does not affect memory for binding more than for the features. However, they found that backward counting disrupted performance in all the three experiments with visual materials. This is consistent with studies based on executive processes in visual memory (Allen et al., 2006, 2012; Morey & Bieler, 2013; Morey & Cowan, 2004, 2005). For example, Morey and Bieler (2013) examined how a concurrent attention-demanding task can affect memory for binding features, and features. They found that domain-general attention has an essential role in visual memory with no evidence of differential effects of dividing attention during retention of features only or binding. They also observed that a strong interference effect is provoked by a non-visual concurrent task during maintenance such as tone classification trials and dual-task trials. These findings correlate with results obtained in other studies which demonstrate that storage capacity in visual short-term memory is related to attentional selection (Vogel, McCullough & Machizawa, 2005) without separate resources for domain-general attentional processes and visual-spatial storage (Stevanovski & Jolicœur, 2007; Vergauwe, Dewaele, Langerock & Barrouillet, 2012). Morey and Bieler (2013) concluded that the secondary task cost is similar for binding and feature judgments, in line with the results of Allen and colleagues (2006).

From the experiments conducted by Allen and colleagues (2014) two interesting observations emerged about the role of executive functions and recency effects in memory for visual object sequences. They observed that the executive control is necessary to retain items that appear earlier in the sequence of information, although it is not crucial for recently encountered stimuli as they seem to be maintain in automatic manner. These findings suggested that when new information enters in the environment this does not need the involvement of the executive resources, because it can be immediately processed by working memory. In a different way, the episodic buffer can be activated to store information consciously. Its focus of attention supports the integration between new automatically encoded stimuli and older information, which need to be preserved (Baddeley et al., 2011). This last process seems to require an internally oriented cognitive control, but it does not explain the impact of concurrent tasks on coexisting present stimuli (Allen et al., 2006, 2012). This can be explained considering that both automatic and cost free encoding and storage within the focus of attention is limited in capacity. On the contrary, executive resources are required when there are multiple items to identify and recall (Allen et al., 2015). This is also the conclusion of a study conducted by Makovski, Sussman and Jiang (2008) who described the importance of the focus of attention on a single stimulus among other stimuli in order avoid external interference. Allen and colleagues (2015) concluded suggesting two components in serial visual working memory. The first component seems to be automatic and its likely activated with every item, but is only useful for the final item without the involvement of executive control, while the second is sensitive to executive load. The latter concerns the maintenance of earlier stimuli and shows an equivalent influence for both individual features and bound objects (Allen et al., 2015).

1.3.6 Cross-Domain and Cross-Modal Binding

The ability to integrate different forms of information is a crucial ability for human mind in particular for reasoning and problem solving. To date, it can be noted that there is a limited amount of research investigating the interactions among working memory components. Even less is the number of studies examining the influence of semantic knowledge and verbal coding on visual working memory tasks (Brown & Wesley, 2013). This is surprising considering that the distinction between visuo-spatial and verbal working memory combined with long-term memory is one of the key features of the multi-component working memory model and it was the main motivation for the introduction of the episodic buffer concept (Baddeley, 2000). The understanding of working memory for verbal–spatial associations is relevant for both practical and theoretical causes, among other reasons, it can be useful to describe in depth working memory capacity (Cowan, Saults & Morey, 2006). It is clear from the literature that separate systems cooperate in binding information in order to be processed and stored (De Renzi & Nichelli, 1975; Baddeley, 2000, 2007; Logie et al., 1990; Logie & Van der Meulen, 2009). Binding can be possible among information both from different domains, such as spatial, visual and haptic, and modalities, auditory and visual for example (Allen, 2015). According to the model by Baddeley (2000), these processes are coordinated by episodic buffer, while other models of working memory do not consider the role of the episodic buffer as they do not indicate different subsystems (Cowan, 1998; 2005; Engle et al. 1999). The episodic buffer has been described as a system which holds integrated features in a unitary representation or object instead of single separated features (Repovs & Baddeley, 2006), similarly to the conception of the domain-general focus of attention by Cowan (2001, 2005).

It has been observed that there are several forms of binding, some of them appear to be automatic, whereas others require additional processes to link different type of features. Information to bind in memory may come from *different domains*, such as verbal and spatial, and *different modalities*, such as visual and auditory (Allen, 2015). In working memory it is possible to make a distinction between format representations. The modality in which the information is processed can be auditory and visual for example, whereas the content might be verbal and non-verbal, which is the actual transferred representation. (Quak, London, & Talsma, 2015).

It has been observed that in Baddeley's multiple component model storage of information with cross-domain features can be possible at both feature and object level. Previous research suggested that cross-domain representations could be held as discrete objects in the working-memory store (Campo, Maestu, Ortiz, Capilla, Santiuste, Fernandez, & Amo, 2005; Cowan et al., 2006; Prabhakaran et al., 2000). At the same time, it is possible that in a cross-domain association features are maintained in a separate way "and their association is either separately maintained apart from those features or deduced from other factors, such as serial order (Cowan et al., 2006)" (Conway, 2009; pp. 2235-2251). These observations on feature binding in visual working imply different possibilities of explanation and theories of working memory about cross-domain associations. Two lines of investigations dominated the research in visual working memory about how conjunctions are remembered: theories of discrete object storage (Vogel et al., 2001) and parallel feature storage (Wheeler & Treisman, 2002). The *discrete object hypothesis*, proposes that cross-domain associations combine and store, in a domain-general working-memory store, verbal and visuo-spatial features together (Morey, 2009). This hypothesis is analogous to Luck and Vogel's (1997) hypothesis on visual binding. They assume that the capacity limit of visual features binding, according to how many features comprise each object, is around three or four objects (Cowan, 2001, 2005). Taking into account the episodic buffer as a domain general working-memory store (Baddeley, 2000), the discrete object hypothesis suggests that features are organised in a unified representation without any additional cost on maintaining features. This representation can be assumed to be a chunk (Miller, 1956) or an object file (Kahneman, Treisman, & Gibbs, 1992) active in working memory both as an object including several features and different representations of the same features.

Whereas, *parallel features hypothesis*, which evolves from Wheeler and Treisman theorisation (2002), is another interesting explanation for cross-domain association maintenance. Their perspective arose from visual feature binding where individual features are maintained in parallel, whereas binding information is maintained independently by another mechanism. Binding is sensitive to interference while features are vulnerable to interference into specific domain. Visual conjunctions seem to be no more vulnerable to interference than their single features (Allen et al., 2006; 2009). However, the same conclusion cannot be drawn for verbal and visual–spatial features binding. The parallel features hypothesis seems to be in accordance with the multiple component model of working memory (Baddeley, 2000). As both of them support the idea that features are maintained in independent and separate stores. Both of them also share the idea that binding information is vulnerable to general interference, whereas only domain specific interference has an impact to the feature information (Morey, 2009).

It can be assumed that there is a domain-general store that maintains arrays of letter–location associations included in the multiple-component model of working memory as episodic buffer. At the same time, another memory array can maintain a list of letters with the auditory–verbal store while in the visuo-spatial store might be maintained spatial representation. These representations may not interfere with one another and they may be subject to interference from domain-specific stimuli, whereas binding preserves information from domain-specific interference through the domain-general working-memory store. In the end, the parallel feature storage explanation seems to be improbable

and did not receive support from the investigation conducted by Allen, Baddeley and Hitch (2006).
Recently, it has been observed that it is possible to assess recall between spatial and verbal domains (Langerock, Vergauwe, & Barrouillet, 2014; Morey, 2009). Specifically, simple combinations of features within domains (Allen, Baddeley, & Hitch, 2014) and also across different modalities (Allen et al., 2009).

Verbal and spatial information can be bound together. The evidence of this association comes also from studies that analyse the role of switching attention between properties of integrated working memory items. Bao and colleagues (2007) observed that items were faster memorised when switching attention between verbal and spatial features from the same object was required, compared to when it was asked to switch attention between properties of different objects. Elsley and Parmentier (2009) found that memory for letter and location binding in working memory was better and faster when stimuli were presented in conjunction rather than being displayed separately. At the same time, the performance was reduced when a demanding tone-judgment task was added as a concurrent load. The results of this experiment are in accordance with Prabhakaran and colleagues (2000) conclusion about the role of attention in cross-domain binding. This is a widely cited study as shows evidence on verbal-spatial binding in a unified object in working memory. In their study, using functional imaging to identify brain regions involved in the binding of letters and locations discovered a greater prefrontal activation for this kind of task. Displays of four letters were administered in different spatial conditions, both in bound presentation and separate presentation. Stimuli were either placed within a specific spatial location or in the centre of an imaginary ellipse without any spatial information. Specifically, the area of activity was larger when maintaining integrated rather than disintegrated representations. The relevance of the right anterior prefrontal cortex to bound information was also noticed comparing blood-oxygen-level-dependent (BOLD) activation both in the bound and separate condition of presentation. This brain area seems to be the neural substrate of cross-domain objects in working memory. Moreover, through this innovative experiment has been also clarified the role of frontal lobe, which seems to be specialised in maintaining working-memory representations from verbal and spatial domains. Likewise, the prefrontal cortex, responsible for integrating multiple forms of information, appears to be involved in high-level cognition which requires flexible mental representations. Binding letter to spatial location can enhance memory for the constituent elements. Faster responses were also noticed for congruent targets, in respect to the original binding, comparing to incongruent materials. However, they concluded that the letter and location associations were stored as distinct objects in general working-memory storage (Prabhakaran et al., 2000).

The role of attention in cross-domain association has been also explored by Langerock and colleagues (2014). They found that the same amount of attentional resources is required for single features and verbal-spatial associations for them to be maintained. The capacity limit for cross-domain associations was also investigated. A complex span task paradigm was administered, asking to participants to memorise verbal-spatial cross-domain associations such as letters in location. At the same time they had to perform tasks with various level of demand in verbal, spatial, and attentional components. They demonstrated that the capacity limit for cross-domain associations is lower than the capacity limit for single features, and the maximum can be composed by three elements. In spite of these capacity limits, a reduction in attentional resources appeared in a similar decrease in maintenance performance for both cross-domain items and single features. This evidence has led to the conclusion that there is no need for supplementary attentional demand to maintain cross-domain multi-feature materials. The authors conducted a second study which shows that domain-specific information such as verbal or spatial was not affected in the maintenance of cross-domain information. This seems to indicate a distinction and independency between the domain-specific buffers and the episodic buffer. In summary, Langerock and colleagues (2014) confirm the role of a central component of limited capacity for the maintenance of cross-domain information which is not attention-dependent, supporting the episodic buffer hypothesis.

Further evidence about the relevance of the central executive comes from the study in visual working memory carried out by Brown and Wesley (2013). In this study visual matrices from Visual Pattern Test (VPT; Della Sala et al., 1999; Della Sala, Gray, Baddeley, & Wilson, 1997) were used. Some of those matrices can be coded verbally applying verbal labels to the stimuli. Brown and Wesley (2013) divided the stimuli in low and high verbal coding task. They observed that in the high verbal coding version visual working memory capacity was better than the low coding version. They noticed that the suppression of central executive deletes the advantage of the high verbal coding task. This seems to imply that central executive resources regulates the benefit associated with verbalisation, allowing a better visual memory.

It has been shown that binding of conjunctions of visual stimulus elements process automatically without the involvement of the executive attentional processes (Allen et al., 2014; Allen, Hitch, Mate, & Baddeley, 2012). This evidence lead to the conclusion that binding processes in the episodic buffer can perform mostly independently of the central executive, contrarily of initial theorisations (Baddeley et al., 2011). However, much of the information that has been retained in working memory is abstract, such as concepts, problem solving (Phillips, Gilhooly, Logie, Della Sala, & Wynn, 2003) and propositions (Haarman, Davelaar, & Usher, 2003). Working memory capacity for abstract types of information is a not well explore area as Cowan et al. pointed out (2006).

Another study used a well known task, such as binding of letters and locations, investigating the neural correlates of *age-related* differences in binding of verbal and spatial information (Meier, Nair, Meyerand, Birn & Prabhakaran, 2014). Event-related working memory tasks was used and it was found that older adults did not display the greater unbound than bound task activity that younger adults performed. The group of young adults showed the activation in bilateral inferior parietal lobule, right putamen, and globus pallidus during the encoding phase. While the cerebellum was involved at the maintenance (Meier et al., 2014). The authors conclude that the performance in binding tasks with letters and locations is not efficient in older adults as it is in younger adults.

Similarly, there are only few available studies on *childhood* developmental changes on binding verbal-spatial information in working memory (Cowan et al., 2006). The ability to retain associations such as between parts of object and between objects and their spatial information it has been noticed to improve with age. It appears to progress with development in infancy (Oakes, Ross-Sheehy, & Luck, 2006) and childhood (Cowan, Naveh-Benjamin, Kilb, & Saults, 2006; Lorsbach & Reimer, 2005; Sluzenski, Newcombe, & Kovacs, 2006). Only a small amount of research has been conducted in this area with children. However, it has been observed that children are capable to create association for example between names of body parts (Johnson, Perlmutter, & Trabasso, 1979) or detecting objects in maps (Uttal & Wellman, 1989). This capacity improves early during primary school years as the working memory capacity rises gradually until adolescence (Gathercole et al., 2003).

With the increase of the number of experiments demonstrating that items can be retained as bound representations in memory, recently more attention has been given to the ways in which different features are bound together. Guérard, Morey, Lagacé and Tremblay (2013) examined the importance of the verbal and spatial characteristics in serial memory for visual stimuli, asking participants to memorise the order of letters presented visually in different locations. The recall of the spatial locations of letters was affected by the manipulation of the phonological similarity of the letters. However, no effect on recall of the letters was associated with the increase of the complexity of the spatial pattern. They concluded that verbal-spatial binding for visual information is asymmetric (Guérard et al., 2013).

A study conducted by Cowan and colleagues (2006) proposed that when feature maintenance is defective a cross-domain object maintenance can be stimulated. From his point of view, in order to maintain verbal and spatial information, different combinations of resources need to be engaged under different circumstances. Another relevant factor in the environment that can have a significant impact on binding is the presence of a domain-specific interference (Morey, 2009). In the research study carried out by Cowan and colleagues (2006) participants were administered on a computer a series of arrays of pentagons with names to be remembered inside them. The task was to place names in the correct pentagons. During the interference condition with articulatory suppression was observed that the accuracy of adults subjects were similar to those of 9-year-old. According to Cowan and colleagues (2006) adult subjects seem to have difficulty to separately maintain the two lists of names and locations caused by the absence of strategy. Through this study interesting observations were demonstrated concerning the nature of cross-domain binding in working memory. Morey (2009) speculated for example on the possibility to describe the binding associations as unitary representations in working memory general storage and if within-domain resources can be engaged to maintain separate features. She also observed that the verbal–spatial memory task used by Cowan and colleagues (2006) cannot be regarded as a pure measure of a domain general store.

A study by Maybery, Clissa, Parmentier, Leung, Harsa, Fox, and Jones (2009) described that auditory and spatial location binding is possible. The authors observed that performance was affected by the spatial position in which stimuli introduced aurally was presented in a recognition task for auditory information. In this experiment, when auditory test stimuli were presented in the same position in which they had been memorised by participants, the performance was better than test stimuli presented in positions different from the ones memorised. These results seem to suggest that auditory and spatial information were coded in an integrated way with a greater persistence for such conjunctions than in visual feature binding (Allen et al., 2006). This evidence leads to the conclusion that memory for visual and verbal materials also incorporates information about the spatial location in which those events occur similarly to the memory for locations that can also include information on the stimuli that take place at that location (Caprio, Pardo Moura Campos Godoy & Galera, 2010).

Interactions between domains or modalities can be further detected in order to promote single task performance. It has been observed that verbal coding can be recruited to support visuo-spatial working memory (Brown, Forbes, & McConnell, 2006; Mate, Allen, & Baques, 2012). Visual representations could be temporarily bound with semantic information from long-term memory and directly activated (Mate et al., 2012). At the same way, it can be possible that retrieve long-term stored semantic knowledge with reference to the abstract visual representations may be certainly demanding (Verhaeghen et al., 2006).

1.3.6.1 Cross-modal interaction

These theorisations on the visual working memory domain have been explored through the administration of the Visual Patterns Test (VPT; Della Sala et al., 1999; Della Sala et al., 1997) a well-known test which measure visual working memory. This test is composed by a visual matrix-type task with abstract stimuli difficult to code verbally. However, it has been detected that these stimuli can be responsive to verbal coding and as a consequence visual working memory capacity has been found superior when there was increased availability of verbal coding (Brown et al., 2006). These findings support the dual-coding theory by Pavio (1971; 1991) as memory capacity improves in connection with the availability of verbal and visual coding. The Visual Patterns Test has been used such an ideal tool to clarify interactions among working memory systems and between working memory and long-term memory and as well to understand how can be enlarge visual working memory capacity. Among the potential components that could allow a better visual memory associated with increased verbalisation, central executive seems to be responsible of this benefit (Brown & Wesley, 2013); whereas, the phonological loop appears not to be associated with higher verbalisation.

Brown and colleagues (2006) investigated, for example, the advantage of using verbal coding in a visual matrix task, the Visual Patterns Test (Della Sala et al., 1999). They found that the accessibility of verbal coding influences the performance on VPT adopting a dual-coding strategy. This supports the dual-coding theory by Pavio (1991). The availability of verbal and visual information reinforces memory capacity (Brown et al., 2006). Some verbal coding patterns were more available than others when verbal coding was higher using a modified version of VPT (Brown et al., 2006). With a similar aim to investigate the influence of a verbal task on memory for coloured shapes, Mate and colleagues (2012) administered a task composed by four visual items, while participants were asked to repeat aloud words that differ for level of imageability and congruence to the task. Results indicate that words with a defined meaning interfered more than abstract words with a different effect on the performance. Taking into account these findings, the authors (Mate et al., 2012) concluded that the content of what we say is important, as it can have a direct effect on visual working memory task. In the same way, visual and spatial working memory information can be a useful support on verbal memory recall through the use of strategies (St. Clair- Thompson & Allen, 2013) and automatic binding. Exploring through five experiments the function of visuo-spatial support in both forward and backward digit recall, evidence of the function of visual imagery in backward digit recall was observed. Moreover, these kind of results have been demonstrated by several studies, which clarifies that visuo-spatial representations can support verbal memory (Paivio, 1991; Ueno & Saito, 2013). Paivio (1991) for example, conducted many studies on imagery and verbal processes through the dual coding theory (DCT) of memory and cognition. This theory evolved from experimental investigations on the function of imagery in associative learning (Paivio, 1963, 1965). From this perspective it would seem that concrete words or sentences are recalled better than abstract. The interpretation of this effect relies on the imagery as an integrative mechanism in associative memory and it seems that the role of the imagery is an additive supplement to the verbal code in items to be remembered (Pavio, 1991).

Another study that tested the role of visual representations in memory for spoken verbal materials was carried out by Ueno and Saito (2013). They tested two kinds of learning in two experiments. In the first study they found a significant effect of word concreteness in paired-associate memory than in serial-order memory. In the second experiment, they noticed that when participants were asked to manage the information within working memory, irrelevant visual stimuli effect was boosted. For this second study, participants had to maintain specific items within working memory, instead of depend on long-term memory. The presence of cue repetition in paired associate memory was manipulated in order to investigate the dynamic visual noise approach (Quinn & McConnell, 1996). Ueno and Saito (2013) concluded that input from irrelevant visual stimuli can affect visual representations of verbal materials (Ueno & Saito, 2013). This effect may result less strongly when long-term memory for immediate recall supports working memory information. Visual codes of verbal material seems to have an important role in paired-associate memory than serial-order memory. Visual codes can be used to reinforce paired information within working memory (Ueno & Saito, 2013).

A similar kind of investigation has been conducted by Caprio and colleagues (2010). In their study they tried to understand if the availability of visual and verbal information could result in a better performance on a spatial location task rather than when only one sensory modality was used (Walker, Hitch, & Duroe, 1993). In this study participants were asked to memorise four different stimuli on a monitor which were presented in random temporal and spatial order. After a retention interval, participants were required to recall the original location of the stimuli. In order to perform this kind of task participants were asked to bind storage of the location and identity of stimuli. The authors believed that this task was appropriate to evaluate binding of the location with visual and verbal information. Visual stimuli were composed by schematic drawings of faces while verbal stimuli were represented by familiar names, object names, and pseudo words. These materials were chosen in order to define two levels of difficulty, as memory capacity for common words is larger than in pseudo words (Gathercole, Pickering, Hall, & Peaker, 2001). Memory for familiar names is supposed to be superior to pseudo words, as the latter involves short-term memory while the former are require long-term memory storage (Ward, Avons & Melling, 2005). However, this was not found in this study. Investigating whether memory for binding between verbal and visual identity can be facilitated by the two types of information, no advantage to boost memory for spatial location was found. This experiment does not support the benefit of cooperation between visual and verbal information as a preference for verbal information, when both types of information were available was observed (Caprio et al., 2010). They did not endorse incidental binding between the two systems. They claimed that their findings showed a lower performance when both types of features needs to be coded. Caprio and colleagues

(2010) observed that they compete for the same processing resources. In conclusion, this study supports the idea that binding between spatial location and stimulus identity relies upon the nature of the bound information with a preference of verbal information if they are available. No evidence of incidental binding of verbal and visual information was found (Caprio et al., 2010).

According to the multicomponent working memory model, materials presented visually can be encoded and stored verbally through the phonological loop and at the same time the visuo-spatial sketchpad can process verbal stimuli in a visual way (Baddeley, 2007; Logie, 2011). This is one of the main strengths of the multi component model together with the role covered by the episodic buffer as a multimodal temporary storage linked with long-term memory. This allows the use of semantic codes from long-term stored knowledge applied to new visual materials. The episodic buffer does not require the involvement of attentional resources of the central executive in order to store multimodal information (Allen et al., 2006; Baddeley et al., 2011; Brown & Brockmole, 2010). There are situations in which episodic buffer storage necessitates of the central executive to process information such as when semantic knowledge is related to the temporary storage of visual stimuli (Brown & Wesley, 2013). This possibility is also described by other models of working memory that emphasise the role of attention storing information in the short-term system (Barrouillet, Bernardin, & Camos, 2004; Cowan, 2005; Kane & Engle, 2002). The model by Cowan (2005) specifically highlights the focus of attention permits the temporary activation of long-term memory information (see chapter one, section one on working memory models).

1.3.7 Visuo-spatial bootstrapping

A recent series of studies demonstrated the presence of implicit cross-modality feature binding (Darling & Havelka, 2010; Darling, Allen, Havelka, Campbell, & Rattray, 2012; Darling, Parker, Goodall, Havelka, & Allen, 2014; Allen, Havelka, Falcon, Evans, & Darling, 2015). Memory for information presented visually for verbal serial recall has been demonstrated to be superior when the visual display is arranged in a familiar spatially distributed pattern, such a telephone keypad, in comparison to when the numbers are presented one after another in a single location. This improvement of memory performance is likely due to the integration of visuo-spatial information when it was available in the display. Implicit bindings of visuo-spatial information and verbal information seems to facilitate performance in children (Darling et al., 2014), young adults (Darling et al., 2010, 2012), and older adults (Calia, Darling, Allen, Hevelka, 2015; see chapter three). It seems to support recall of verbal information only when subjects have precedent knowledge of such associations. This effect has been called 'visuo-spatial bootstrapping' (VSB; Darling et al., 2010), because verbal memory performance is bootstrapped by the integration of visuo-spatial information which are available in the familiar keypad condition, but not in the single item condition.

In most of the studies on visuo-spatial bootstrapping, participants were shown sequences of digits for immediate recall. When these were presented by 'lighting up' a sequence of digits in a spatial array that was arranged as a traditional telephone keypad, digits were better remembered than if they were presented as single digits in the centre of the screen. This was assumed to reflect the fact that visuo-spatial information, either in working memory or long-term memory, is bound to the verbal digit information, facilitating performance (Darling & Havelka, 2010; Darling et al., 2012, 2014).

The task used does not explicitly ask participants to bind information, but to memorise sequence of numbers as best they can. At the same time what memory strategy to use to perform the task was not suggested. Visuo-spatial bootstrapping demonstrates the existence of an implicit cross-modality feature binding.

Visuo-spatial bootstrapping is an effect where visuo-spatial memory is combined with verbal memory. The majority of studies of binding that have investigated the function of episodic buffer have been used tasks that explicitly require binding between features held in working memory. The bootstrapping task is different from these as it requires the subjects to remember only a single verbal attribute but also allows the chance of retaining information that can support performance from the visuo-spatial modality. For these reasons, the bootstrapping task is a technique that can be used to examine implicit binding effects. These recent investigations on bootstrapping effects clearly illustrate a link between theoretically separate visuo-spatial and verbal memory systems.

The revised model of working memory by Baddeley (2011) seems to offer a reasonable explanation through the episodic buffer by which visuo-spatial information from long-term memory can be bound with short-term memory information resulting in superior recall performance. There are several real examples from daily life in which keypad arrays are frequently used to arrange digits, such as telephone keypads and ATM machines. It has been suggested that motor encoding strategies adopted to enter a PIN and to dial a telephone number based on familiar keypad arrays are favourable to long-term memory for digits (Fendrich, 1998). This observation supports the idea that memory for digits can be better in a keypad arranged in a familir way.

Visuo-spatial bootstrapping offers support to the role of the episodic buffer added to the working memory model (Baddeley, 2000). This effect requires the presence of a familiar representation in long-term memory because only well-known displays, such as phone keypads, draw out the effect (Darling et al., 2012). Thus, verbal–spatial binding is crucially dependent on knowledge and associations already present in long-term memory. A similar pattern has been noticed when spatial material has to be remembered with long-term spatial memory that influences working memory for spatial configurations (Brown & Wesley, 2013). It seems that that long-term memory has a relevant role and can significantly facilitate recall in working memory.

Four main studies have been conducted so far to examine different aspects involved in the visuo-spatial bootstrapping effect.

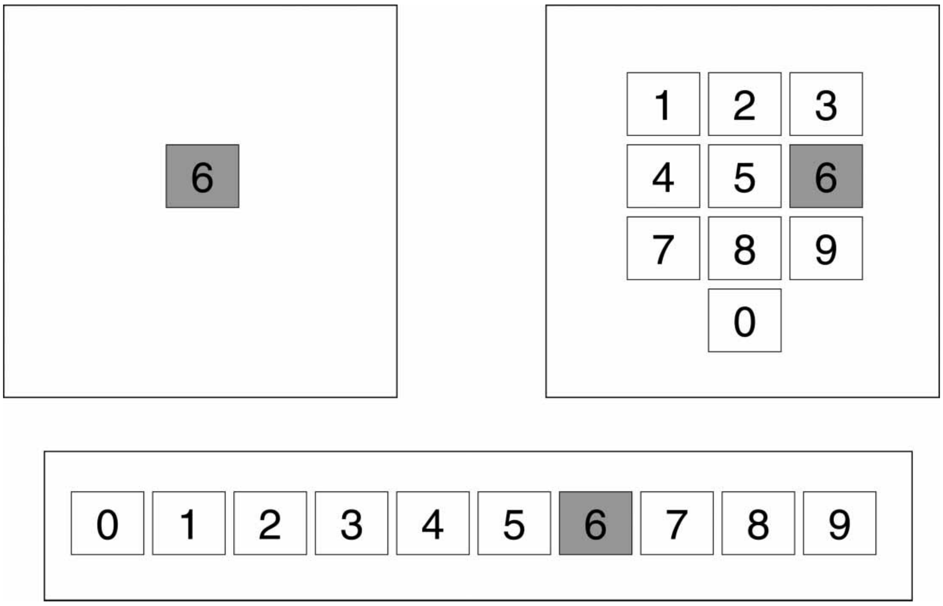
In the following paragraphs previous studies on visuo-spatial bootstrapping (VSB) will be described as it is the paradigm used in the three experimental studies (see chapters two, three and four). To date, there are four published studies on visual-spatial bootstrapping and they will be briefly described one by one explaining in particular both the methodology used and the results obtained.

1.3.7.1 "Visuo-spatial bootstrapping: Evidence for binding of verbal and spatial information in working memory" (Darling & Havelka, 2010) - **First study**

This first experimental investigation on visual-spatial bootstrapping was designed to focus on whether visuo-spatial memory can assist performance of a verbal working memory task. Participants were asked to undertake a visually presented verbal serial recall task in three different display conditions: a single item condition, a linear keypad and a keypad similar to the telephone keypad (see Figure 7).

The difference between these displays lies on the amounts of spatial information available when the to-be-remembered digits were shown. In the single digit condition, a single number was individually presented on the screen of a computer, while in the linear and keypad conditions all digits, from zero to nine, appeared together in the same layout across all trials. In the typical keypad condition digits were presented in the array of a familiar telephone keypad. All items to be remembered (digits from zero to nine) were randomly presented with no digit repeated in any lists. Participants were asked to start pressing a key on the keyboard of a computer. Then, a message appeared on the screen in order to instruct participants on the number of items to remember. After, a fixation cross appeared in the middle of the screen followed by the display with the digits to be remembered. After the digits had been displayed, the message "Recall" appeared in the middle of the screen. Then participants were asked to verbally recall the sequence of digits in the correct order using as much time they need.

Figure 7. Three screen displays used in this study (Darling & Havelka, 2010): static single item display, keypad display, linear display (retrived from Darling & Havelka, 2010; in this picture the grey color is used instead of green as for the other studies).



A main effect of display type was found which reflects the differences across the three conditions in memory performance. Participants performed significantly better in the keypad condition than in the single item and linear condition, whereas the difference between the linear and the single item conditions was not significant. The authors also indicate that the data did not imply the use of a mental number line. If this was the case, performance in the linear display condition would have been better than in the others conditions.

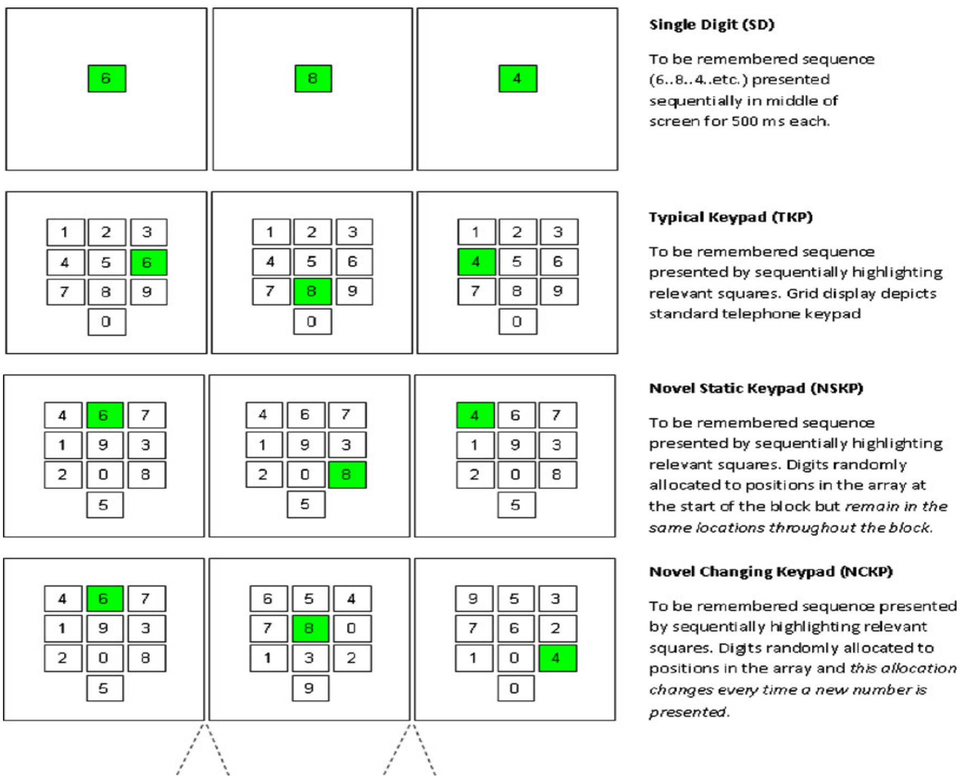
The current findings are consistent with the revised working memory model by Baddeley (2000), as long-term memory potentially played a relevant role. The long-term knowledge can promote encoding and retrieval when it is linked with the verbal memory trace in the episodic buffer. The authors hypothesised that the superior performance in the typical keypad display was due to the integration of long-term knowledge about the familiar telephone keypad. On the contrary, this pattern of results could not be explained through the previous model of working memory as it could not predict any difference between the linear and keypad conditions. This data set support the revised model because in the linear display condition was found no evidence of visuo-spatial bootstrapping

1.3.7.2 "Visuo-spatial bootstrapping: Long-term memory representations are necessary for implicit binding of verbal and visuo-spatial working memory" (Darling et al., 2012) - Second study

In the second study on visuo-spatial bootstrapping the mechanisms behind this effect found in the previous study, were investigated. In particular, the role of long-term memory needed to be explored in depth. The aim of this second experiment was to define whether visuo-spatial coding has a role in temporary memory or whether long-term memory has a crucial role. The main conclusion obtained in this study was that representations in long-term-memory are fundamental in order to obtain a bootstrapping effect.

This time the study utilised four display conditions: the single digit (SD) display, typical keypad (TKP) display, novel static keypad (NSKP) display and novel changing keypad (NCKP) display (see Figure 8). The last two display conditions were not used in the previous study. The novel changing keypad had the same shaped grid of the typical keypad but digits were located randomly rather than a familiar array. Numbers on the keypad were located in the same way throughout all trials in the condition. This condition was added to observe if participants could develop a long-term representation of this new array over several trials administered. This would impact positively in their digit recall performance learning the digit locations. In a different way, in the novel changing keypad display was used a similar keypad array with digits location mapping changing in every new trials. The positions of digits were randomised across all trials. In this way, there was no chance of using knowledge stored in the long-term representation facilitating recall performance as the array was completely unfamiliar.

Figure 8. Four displays used in this study: Single Digit (SD), Typical Keypad (TKP), Novel Static Keypad (NSKP), and Novel Changing Keypad (NCKP) displays of the to-be-remembered digits (retrieved from Darling et al., 2012).



This study replicated the results of the previous study, showing a significant and reliable bootstrapping effect (Darling & Havelka, 2010). In the typical keypad display memory performance was considerably better than in the single digit display as well as in the other two conditions. This evidence indicated that additional spatial information can facilitate immediate serial recall of digits. Noticing that verbal memory was not enhanced in either the novel static keypad or the novel changing keypad compared to the typical keypad display, the authors assumed that the bootstrapping effect requires the link of information between verbal and visuo-spatial working memory and long-term memory.

Findings confirm one time more the bootstrapping effect, proving that it involves long-term knowledge binding visuo-spatial and verbal working memory representations. This then supports the role theorised of the episodic buffer bounding representations from throughout memory without the involvement of attention (Baddeley et al., 2011). However, the data from this study could also be explained through the model of working memory by Cowan (2005) as the episodic buffer is consistent with the focus-of-attention approach. The main difference between them regards the role of attention in the process of binding, because while the episodic buffer is considered free from attention (Baddeley et al., 2011), in Cowan's model attention still has a crucial and essential role. According to these considerations on models of working memory, visuo-spatial bootstrapping seems to firmly support the episodic buffer model as it produces implicit binding without the involvement of attentional resources.

1.3.7.3 "Visuo-spatial bootstrapping: Implicit binding of verbal working memory to visuo-spatial representations in children and adults" (Darling et al., 2013) - **Third study**

This study investigated visuo-spatial bootstrapping in children for the first time. This study was a cross-sectional developmental research project which shows that the trajectory of bootstrapping is independent of the development of verbal and visuo-spatial working memory during childhood.

In order to understand differences among age in children, two groups of children were selected of six and nine year old with a comparison sample of young adults. After an assessment of their knowledge of the standard telephone keypad, children underwent a span assessment. In order to assess maximum span, children were asked to remember random sequences of digits with a single digit display with numbers from zero to nine appearing in the middle of the screen of a computer. The sequence length was incremented a digit at a time until participants failed to recall any sequences of numbers correctly. The maximum span was obtained by the maximum sequence length at which children could recall at least one sequence correctly. Following the span assessment, participants were tested, at their own individual span, in three different displays: the single digit display (SD), the typical keypad display (TKP) and the novel display (NSKP). The results indicated an interesting difference between the two groups of children. Specifically, children of six years of age did not show visuo-spatial bootstrapping effect, while nine year old children perform as adult subjects. Developmental studies have found that working memory capacity gradually increases over time (Gathercole, 1999). In a different way, the bootstrapping effect is absent in six year-olds, but fully present in children of nine years of age. To demonstrae that bootstrapping not proceed along the same trajectory level of maturation as verbal and visuo-spatial working memory.

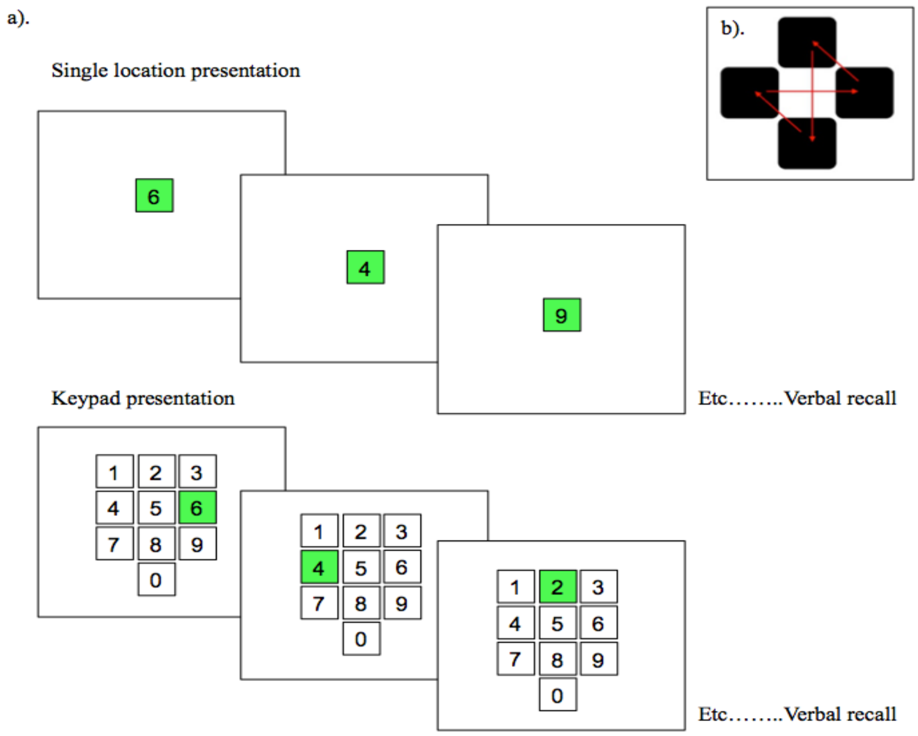
The authors of the study proposed three different explanations to account for this finding. One of these is related to the role of long-term memory which is essential to obtain the bootstrapping effect (Darling et al., 2012). It is indeed possible that it can not be properly consolidated in younger children. Another possible explanation is that it can be difficult for of six year old children to integrate visuo-spatial and verbal working memory with long-term representations. This is the role of the episodic buffer that can have a specific maturation over years. Furthermore, the authors proposed another feasible interpretation which is liked with the use of strategic visuo-spatial resources. It can be possible that six year old children are not able to select an appropriate strategy in order to remember the correct sequence of numbers. For example, evidence from literature indicates that only children older than seven years are capable to convert visual stimuli into a verbal format (Hitch, Halliday, Dodd, & Littler, 1989).

It is clear from these findings that the visuo-spatial bootstrapping effect is quite intriguing. In summary, the data shows that the bootstrapping effect is similar in magnitude in adults as in nine year-old children, but not in six year-olds. This demonstrates that the development of the bootstrapping is different from the maturation of basic working memory functions.

1.3.8.4 "Modality Specificity and Integration in Working Memory: Insights from Visuo-spatial Bootstrapping" (Allen et al., 2015) - Fourth study

This study explored how different capacities within specialised domains of working memory can contribute to facilitate performance on the online combination of verbal and spatial information using long-term knowledge. The effect of verbal and spatial concurrent tasks on memory of visually presented digits was analysed. Young adults undertook both single digit location and typical keypad tasks while they were performing concurrent tasks, such as articulatory suppression and spatial tapping (Figure 9).

Figure 9. Stimuli used in the tree different experiments in the study: a) display condition, and b) spatial tapping layout used in the last two experiments (Allen et al., 2015).



This study investigated the contribution of the two separable verbal and spatial domains for cross-domain binding. Concurrent tasks that involve verbal or spatial processes during stimulus presentation had a negative impact in both display conditions with a different influence according to display configurations (typical display and single digit). The performance of participants in the typical display condition was significantly better than in the single digit condition. Moreover, considering that various types of concurrent tasks have a different impact on the bootstrapping effect, it can be argued that there are an interactive relations between separable, specialised processing capacities, and cross-domain storage. These findings supports the role hypothesised of the episodic buffer as a modality-general storage capacity within the multi-component model of working memory connecting modality-specific subsystems (Baddeley, 2000; Baddeley et al., 2011).

Articulatory suppression influences the maintenance and rehearsal of verbal material especially in the single digit condition of this study. This is due to the dependency on verbal maintenance without any other spatial information in the single digit condition. In the typical keypad condition the availability of a familiar spatial configuration reduced the dependency on verbal working memory and as a consequence the impact of articulatory suppression.

A different impact was obtained with spatial tapping interference on keypad recall as it resulted in destruction of the bootstrapping benefit. This study underlines the crucial role of spatial resources for verbal-spatial binding in the episodic buffer. These results clearly indicate that domain-specific processes are essential for the employment of familiar verbal-spatial associations. If visuo-spatial information is not available as it is loaded by concurrent spatial tapping task, verbal working memory becomes essential for verbal recall. This is one of the main strengths of working memory, being a flexible system expressed in several strategies adopted to cope with different cognitive processes (Logie, 2011).

In the last experiment, when tapping was performed during recall, no interaction was observed between display type and spatial tapping. Spatial processing is essential to the creation of domain-general representations, but not during recall. These observations corroborate the findings obtained by Langerock and colleagues (2014). In their study concurrent tasks loading on verbal or spatial processing were administered during visually presented verbal information spatial locations, or verbal-spatial binding. The authors claimed that the results showed a separation between domain sub-systems and the episodic buffer. Cross-domain associations are maintained within the episodic buffer in a modality-general storage and domain-specific processes making separable contributions during initial encoding (Langerock et al., 2014). They found that the role of attention is

not crucial during the maintenance of feature bindings in visual working memory. Their findings support that in order to maintain verbal-spatial information there is no need for more attentional resources; when compared with verbal or spatial features. Both processes are equally impaired by lack of maintenance of attention (Langerock et al., 2014).
Modality-specific components are involved in digit recall tasks with a relevant role during initial encoding of familiar verbal-spatial associations by visuo-spatial processing. Domain-specific processes can contribute in a different way during the initial encoding, underlying this distinction (Allen et al., 2014). Furthermore, an essential contribution is made also by cross-domain binding and long-term knowledge in order to obtain the bootstrapping effect. Concurrent tapping tasks loading on processes of visuo-spatial sketchpad have a negative impact in memory for dynamic visually presented items (Pickering, Gathercole, Hall & Lloyd, 2001). This can be hypothesised as a reason for spatial tapping effects in the single location condition.
It has been argued that information from different modalities, such as verbal and visuo-spatial, is at first analysed within modality-specific storage and then it is combined within the episodic buffer (Baddeley et al., 2011). These observations are in accordance with Ericsson and Kintsch (1995) position that claim that higher-level processing, before being integrated, needs lower level materials to be initially maintained in specialised store systems. Thus, it seems that modality-specific processes lose their essential role after binding.

In conclusion, it has been demonstrated that the visuo-spatial bootstrapping effect is reliable and shows interesting responses to dual task manipulations. It "emerges at encoding and requires spatial processing resources to support the activation of verbal-spatial associations. Once these are set up within a domain-general storage capacity such as the episodic buffer, spatial processing is then no longer critical" (Allen et al., 2014; p.25).

1.3.7.5 Conclusion on visuo-spatial bootstrapping effect

The "visuo-spatial bootstrapping effect" refers to the finding that information presented visually for verbal serial recall is recalled better, when the visual display is arranged in a familiar spatially distributed pattern, such as a telephone keypad. Moreover, many models of working memory, including the Baddeley's model (2011), are compatible with this effect. For example, considering the model proposed by Unsworth and Engle (2007) (see chapter one) bootstrapping effect can be described as a process where keypad displays support search of secondary memory as results of the additional cues. Overall, long-term spatial memory has been demonstrated to influence working memory for spatial configurations.

This effect uses associations and knowledge between verbal and spatial information that are already stored in long-term memory in order to benefit from verbal-spatial associations. Visuo-spatial bootstrapping seems to be an effective method to investigate interaction between multiple domains of processing and long-term memory. This leads to the conclusion that it can be described as a pattern of expert memory (Ericsson & Kintsch, 1995) recognised across the spectrum of young adult participants (Allen et al., 2015).

Increasing the understanding of the working memory functioning through the investigation of visuo-spatial bootstrapping can open up an opportunity for the development of tests that will be able to assess the episodic buffer, a working memory component for which no measure currently exists - the episodic buffer.

1.4. Working memory in older adults

This section examines working memory in older adults discussing, among other topics, the differential decline in verbal and visual-spatial working memory, changes in executive functions that occur with age and binding processes. As it has been repeatedly observed that working memory declines with age, in study two (see chapter three) it has been investigated any differences of the bootstrapping effect between older and younger adults.

1.4.1 Introduction

Normal ageing is associated with a decline in many cognitive functions (Manan, Franz, Yusoff & Mukari, 2013) including working memory, auditory processing, (Anderson, Parbery-Clark & Yi, 2011; Dew, Buchler, & Dobbins, 2011), attention (Smith, Geva, Jonides, Miller, Reuter-Lorenz & Koeppe, 2001) and long-term memory (Park, Lautenschlager, Hedden, Davidson, Smith & Smith, 2002). Even though memory declines with age, there are no clear explanations about the causes (Kilb & Naveh-Benjamin, 2015). Different hypotheses have been addressed including decrement of speed to process information (Salthouse, 1996), reduction of processing resources (Craik, 1982; 1983), difficulty in inhibition (Zach & Hascer, 1994) and reduction of the ability of binding (Naveh-Benjamin, 2000). Several studies consider working memory a fundamental construct for understanding the changes that occur with the progression of age (Borella, et al., 2009; Borella, Carretti & De Beni, 2008), as it has been repeatedly observed that working memory decline with age (Jost, Bryck, Vogel, & Mayr, 2011; Myerson, Emery, White, & Hale, 2003; Chen, Hale, & Myerson, 2003). There is growing and consistent evidence of a gradual linear age-related decline in working memory in a number of studies, using different modalities and types of stimulus materials administered (Vaughan & Hartman, 2010; for a review see Rajah and D'Esposito, 2005) and regardless of task modality, visuospatial vs verbal (Park et al., 2002).
Cognitive ageing should be seen as a multidimensional and multidirectional phenomenon, as a wide range of research on the effects of age on cognition has revealed at least three different patterns of change of cognitive functions linked with age (Hedden & Gabrieli, 2004). In fact, some features, such as, working memory and processing speed, tend to

show a decline during the life span. On the contrary other functions tend to show only a slight decline in old age and others still tend to remain fairly stable with the progression of age.

Horn and Cattell (1966; 1967) have suggested a distinction between crystallised intelligence and fluid intelligence. The first, strongly linked to culture, is based on information well learned, on knowledge acquired with experience (for example, vocabulary). It seems to remain almost unchanged with the progression of age, and often tends to improve. On the contrary, the fluid abilities refer to capacity that use in an adaptive way the available information for the conceptualisation and the solution of problems, measured, for example, with reasoning tests, such as Raven's Progressive Matrices (Raven, Raven & Court, 1993; 2003). Unlike crystallised skills, this type of intelligence, mostly dependent on biological and physiological factors, tends to deteriorate with the progression of age (Bugg, Zook, DeLosh, Davalos, & Davis, 2006; Salthouse, 1996, 2001). Even from the lifespan perspective proposed by Baltes (1987), it is possible to distinguish between mechanics of cognition, basic mental operations more closely related to biology, and pragmatics of cognition, related to culture. Reasoning, memory and all the other skills that are based on mechanical components and undergo a rapid decline, in contrast to the skills based on pragmatic component (such as verbal skills) which remain stable until late in life. The decline associated with the mechanical component of cognition seems tied to changes of neurophysiology, while changes in the pragmatic component would reflect the effect of accumulation of experience. It must however be noted that in old age it is possible to observe the decline of all the components of intelligence. This is due to the fact that biological factors become increasingly influential and cultural resources less effective in offsetting the loss of fluid abilities.

1.4.2 Basic mechanisms that explain cognitive ageing

It has been widely shown in the literature that, with the progression of age, the rate at which the mental operations are performed (Salthouse, 1996) and working memory decrease (Craik, Morris & Gick, 1990; Park, Lautenschlager, Smith, Earles, Frieske and Zwahr, 1996). It is more difficult to ignore irrelevant information or thoughts or inhibit preponderant responses (Hasher & Zacks, 1988), and is more difficult to remember the context in which the information is presented (Frieske & Park, 1999). As it has been mentioned before, this decline is not generalised, some functions, such as memory or implied semantic knowledge are not very sensitive to the effects of age (Park et al., 1996; Park & Shaw, 1992).

Over the last few decades, it has been proposed that some basic cognitive mechanisms are able to explain the decline of cognitive functioning. They represent the amount of mental energy available to perform a cognitive task (Park, 2000). There is a general consensus that, with the progression of age, these resources would tend to decline by limiting the ability of individuals to perform mental operations (Borella, Cornoldi, & De Beni 2009; Park, 2000).

1.4.3 Working memory

"Rapid growth in the number of older people worldwide has led to an equally rapid growth in research on the changes across age in cognitive functions. Core among these functions are those associated with the processes of moment to moment cognition known as working memory; the ability to keep track of our thoughts, our actions and changes in our environment, that pervades our every waking moment, and is crucial for effective independent living" (Logie & Morris, 2015; pag., xi). Some studies have suggested that working memory can be an important construct in order to understand cognitive ageing as it is involved in several cognitive tasks and it is essential for everyday competence. It has been demonstrated that working memory is compromised in older adults (Babcock & Salthouse, 1990) and it declines at different rates across the life span (Logie & Maylor, 2009). This was also hypothesised to be the main cause of higher order cognitive decline associated with normal ageing (Verhaeghen & Salthouse, 1997).

The decline related to the progression of age in a wide variety of tests of fluid cognition seems, in fact, to be explained by age-related decline in working memory. Particularly in attentional and executive components of working memory (Baddeley, 1989; Engle, Kane & Tuholski, 1999). This is thought to be a direct mechanism (Mayr & Kliegl, 1993) or a mediator between a more general decrease in processing resources and complex cognition (Salthouse, 1996). Evidence demonstrates how the elderly show lower performance in working memory tests than younger (De Beni, Borella, & Carretti, 2007; De Beni &

Palladino, 2004; Gick, Craik & Morris, 1988; Robert, Borella, Fagot, & Lecerf de Ribaupierre, 2009; Vecchi, Richardson & Cavallini 2005; for a meta-analysis, see Bopp & Verhaeghen, 2005). The decline in performance on tests of working memory with the progression of age has been confirmed, not only in cross-sectional studies that compare groups of extreme age, but also by lifespan studies that show a linear age-related decline (Borella et al., 2008; Jenkins, Myerson, Hale, & Fry, 1999; Park et al., 1996; 2002). The decline in working memory starts in middle adulthood and become more visible in old age, around 60 years old (Craik & Salthouse, 2000; DeFrias et al., 2007; Li, Lindenberger, Hommel, Aschersleben, Prinz, & Baltes, 2004; Park et al., 2000).

The debate in the literature on changes due to age in working memory has focused on two main aspects. First, the question was raised whether the working memory tests are more sensitive to the effects of age compared to span test; and then, the second important question concerns the debate featured on a different possible decline in verbal and visual-spatial domain.

1.4.4 Passive remembering and active processing

Working memory may be described as the dynamic relationship between passive and active transformation or manipulation of information in memory. An important characteristic is its limited capacity. This implies that resources should be shared between maintenance and processing (Bopp & Verhaeghen, 2005). As it has been described in chapter one, there are differences between short-term memory (passive) and working memory (active). The first require to bear in mind a sequence of letters or digits for a few seconds before repeating them in the correct order. Task demands are, therefore, related to the maintenance rather than processing. The active tasks require, instead, more complex processes, because the participants are asked to manipulate or transform the material (such as for example Digit span backward test).

Several lines of evidence indicate that there is a greater decline due to age in working memory compared to the maintenance of passive information (Borella et al., 2009; Craik & Jennings, 1992; Dobbs & Rule, 1989; Vecchi & Cornoldi, 1999; Vecchi et al., 2005). A meta-analysis conducted by Bopp and Verhaeghen (2005) concluded that, although the differences of age are evident in both active and passive tasks, the latter are less sensitive to the effects of age compared to tests that require a greater attentional control.

Conflicting results emerge instead regarding tests of digit span backward, which not only require a mere maintenance information (such as in the tests of short-term memory) but also reordering them. Some research has shown a decline due to age in this kind of test, without evidence of an effect of age in short-term memory tests (Babcock & Salthouse, 1990). On the contrary, other studies have shown no decline for both types of tests (Myerson et al., 2003; Park et al., 2002). In their meta-analysis, Bopp and Verhaeghen (2005) found that performance in tests of digit span backward are in the middle between the passive and the active tests. The model of working memory proposed by Cornoldi and Vecchi (2000; 2003) seems to explain this pattern of results. The two authors consider working memory as a continuum based on the degree of active processing of information required in a task and another dependent on the nature of the information to be processed. Specifically, Vecchi and Cornoldi (1999) emphasise the importance to distinguish between passive and active processing in maintaining in order to interpret the decline dependent from age in tests working memory.

The selective impairments of the executive component of working memory was investigated in relation to different theoretical perspectives. For example, Salthouse and Mitchell (1989) distinguished between the structural capacity (amount of information that can be maintained) and operational capability (amount of processing necessary to perform the task). A series of experiments confirmed the possibility of a selective age-related decline of the operational capacity, without compromising the structural capacity (Salthouse, 1987; Salthouse & Mitchell, 1989). Mayr and Kliegl (1993; Mayr, Kliegl & Krampe, 1996) have highlighted the difficulties for older adults to integrate and coordinate different information compared to tasks in which information can be processed sequentially. According to the two authors, there would be two factors that can explain the age-related differences in working memory: sequential complexity, determined by the number of independent processing components involved in a task, and the coordinative complexity, defined as the coordination of the various components within working memory.

However, it might argued that the differences between active and passive tasks are due to the increased difficulty of active tasks. Vecchi and colleagues (2005) showed that performance in active tests declined continuously throughout the life span, while the decline in the passive trials is evident only later in life, when it increases the weight of the biological factors. This pattern of results emerges when both the passive trials are easier than those active when the active tests are easier and passive, so they are no matter how difficult the task.

1.4.5 Neuroimaging studies

The anatomy and neurochemistry of the brain and the functional dynamics are subject to considerable age-related transformation (Madden, Bennet & Song, 2009; Raz, 2004; Raz, Lindenberger, Ghisletta, Rodrigue, Kennedy, & Acher, 2008; Salat, Buckner, Snyder, Greve, Desikan, Buse, et al., 2004; Westlye, Walhovd, Dale, Bjoornerud, Due-Tonnessen, Engvig, Grydeland, Tamnes, Ostby & Fjell, 2010). The cognitive decline is analogous with the anatomical changes and working memory is one of the functions that decreases with the progression of age (Baddeley, 2003). The age-related decline in working memory (and other cognitive functions) is parallel to the decline of the prefrontal cortex that seems to play a relevant role within the working memory network (Lindenberger, Burzynska & Nagel, 2013; Raz, Lindenberger, Rodrigue, Kennedy, Head, Williamson, et al., 2005). Furthermore, dorsolateral prefrontal cortex activity seems to be associated with deficits in executive behaviours in older adults (MacPherson, Phillips, & Della Sala, 2002). While age-related cognitive decline has been linked with fronto-temporal circuitry (Brickman, Zimmerman, Paul, Grieve, Tate, & Cohen, 2006).

It has to be noticed that both genetic differences and experience can modulate brain decline and with advancing adult age the individual differences increase in working memory (Lindenberger et al., 2013; Schmiedek, Lovden & Lindenberger, 2009).

The number of studies using fMRI to investigate working memory ageing is increasing over the last decades noticing age differences in functional brain (Spreng, Wojtowicz & Grady, 2010). These changes are explained in different ways. Over activation has been observed in older people compared to younger both in the same regions and in additional regions recruited by young adults. The activation of additional regions seems to create a compensatory functions (Cabeza, 2001; 2002; Cabeza, Anderson, Locantore, & McIntosh, 2002; Reuter-Lorenz, Jonides, Smith, Hartley, Miller, Marshuetz & Koeppe, 2000) that can also be dysfunctional (Logan, Sanders, Snyder, Morris & Buckner, 2002) because it can be a sign of inefficient neuromodulation and inhibition (Li, Lindenberger & Sikstrom, 2001; Park et al., 2002; Reuter-Lorenz et al., 2000). It has been hypothesised that compensatory over activation can arise in response to defective processing especially in frontal area (Reuter-Lorenz & Mikels, 2006). The involvement of additional regions of the brain can work as a scaffold to protect working memory (Park & Reuter-Lorenz, 2009).

It is interesting to note that neuroimaging studies have shown that both the executive component and maintenance of information decline with the progression of age (Reuter-Lorenz, 2002; Reuter-Lorenz, Marshuetz, Jonides, Hartley & Smith, 2001; Reuter-Lorenz and Sylvester, 2005). Reuter-Lorenz (2002; Reuter-Lorenz et al., 2001) has formulated the *hypothesis of selective compensation*, according to which, the executive component can compensate the deterioration due to age. In other words, the elderly seem to recruit additional brain areas. Including those that control the executive processes, to perform passive tasks. In consequence of this over-recruitment to control cognitive performance in relatively low levels, the elderly have fewer resources available to perform tasks that require a greater attentional control. Which therefore are most sensitive to the effects of age. The authors (Reuter-Lorenz et al., 2001) concluded that the measures of working memory should be considered along a continuum in which the degree of attentional control depends not only on the task but also by age of the participants. The elderly, for example, in order to compensate the decline during the maintenance tests, need to recruit areas involved in more complex processes that are activated in young people only in tests that require more attentive resources.

It is clear that older adults have worse performance than young people in span tests, and particularly with those requiring a high executive control, independently of type of material presented (De Ribaupierre & Lecerf, 2006; De Ribaupierre & Ludwig, 2003; Park et al., 2002). As it was described above, an interesting perspective has been proposed by Cabeza, Anderson, Locantore, McIntosh (2002) and Reuter-Lorenz (2002), who hypothesised that alternative networks can be recruited when older adults are involved in complex tasks. This assumption derives from the model of Hemispheric Asymmetry Reduction in Older age (HAROLD; Cabeza, 2001; 2002; Cabeza et al., 2002). This model seems to support a bilateral recruitment of the prefrontal cortex (PFC) in older age whereas young subjects activate only one hemisphere. Older adults may utilise verbal working memory to maintain performance on skill learning tasks (Bo et al., 2012) as a consequence of relatively faster decline in visuo-spatial working memory. In typical young adults, brain activation is predominantly left lateralised for verbal working memory and right lateralised for visuo-spatial working memory. While older adults show more bilateral activation patterns for both types of memory (Reuter-Lorenz et al., 2000). Consequently, it might be expected that laterality patterns decrease and visuo-spatial working memory also declines with age.

Another relevant perspective is the Scaffolding Theory of Aging and Cognition (STAC; Park & Reuter-Lorenz, 2009). This model suggests that one of the outcomes of an adaptive brain is that it engages in compensatory scaffolding. This seems to occur in response to the challenges posed by declining neural structures and function, increasing frontal activation with age. According to the authors (Park & Reuter-Lorenz, 2009), STAC is a process that involves development of alternative and complementary neural circuits to achieve a cognitive goal. This process seems to be present across the life span.

It is also noticed that over recruitment of the prefrontal cortex or other brain areas can be beneficial in easy tasks, but it cannot be increased when the difficulty of the task rises (Reuter-Lorenz & Mikels, 2006). The compensatory over-activation can be described as the neural equivalent of raised effort due to age-related neurobiologcal deterioration, while a successful ageing would be characterised by an absence of over-activation (Nagel & Lindenberger, 2015).

Another interesting observation about normal ageing is that it affects the relation between different brain regions apart from altered functional brain activation (Bennet, Sekuler, McIntosh, & Della-Maggiore, 2001). "According to the Disconnection Hypothesis, age differences in cognitive ability are in part due to a disconnection of task-relevant brain regions caused by white matter changes" (Nagel & Lindenberger, 2015, pp.132). Many studies show that the decline of the white matter integrity is related with the progression of age and this has been linked with cognitive performances and effective connectivity of the brain (Bennet et al., 2001; Burzynaka, Preuschhof, Backman, Nyberg, Li, Linderberger et al. 2010; Sullivan, Rohlfing & Pfefferbaum, 2010).

1.4.6 Differential decline in verbal and visual-spatial working memory

Only few studies have directly compared the effects of age in verbal and visual-spatial working memory tests, reporting mixed results. A series of evidence has, in fact, suggested that older people show more difficulties in processing visuo-spatial information than verbal material (Bopp & Verhaeghen, 2007; Jenkins et al., 2000; Myerson et al., 1999; 2003; Tubes & Calev, 1989; Verhaeghen et al., 2002). For example, Myerson and colleagues (1999) found that older adults show a lower performance in tests of spatial span than younger, although both groups of age have similar performance in tests of verbal span. Also, Jenkins and colleagues (2000) reported differences in trials with visual-spatial stimuli compared to tests with verbal stimuli.

Similar results are obtained by Bopp and Verhaeghen (2007) who have confirmed that the effects of age are larger in visual-spatial tests than verbal tests, taking into account both accuracy and reaction times. In an attempt to explain the reason of a greater difficulty encounter by the elderly in processing visual-spatial than verbal material. Jenkins, Myerson, Joerding and Hale (2000) analised numbers of psychological and neurobiological mechanisms. As far as the psychological mediators, the authors suggested that the slowdown caused by age is especially pronounced in the visual-spatial domain (Hale & Myerson, 1996). The authors called into question the distinction between fluid and crystallised intelligence. The visual-spatial skills may be much more linked with fluid intelligence while the crystallised skills seem to be related to verbal memory (Baddeley, 1996). This decline might at least partially explain the difficulties faced by the elderly in a wide variety of tests of fluid cognition (Baddeley, 1989; Dobbs & Rule 1989; Verhaeghen & Salthouse, 1997). In contrast of a minimal decline in crystallised intelligence (Schaie, 2005). It is interesting to notice that several studies underline the correlation between visual working memory with general fluid intelligence and verbal working memory to crystallised intelligence (Bergman & Almkvist, 2013; Dang, Braeken, Ferrer, & Liu, 2012; Haavisto & Lehto, 2004). This can be associated with increased executive demands of common visuospatial working memory tasks (e.g., Vandierendonck, Kemps, Fastame, & Szmalec, 2004). The relationship between visuo-spatial working memory and fluid intelligence specifically seems to be more stable than the relation between verbal-numerical working memory and crystallised intelligence. Even if the strength of the relationship varies in different studies (Colom, Flores-Mendoza, & Rebollo, 2003; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Verguts & De Boeck, 2002). These patterns of relationships provide further evidence to the argument that working memory is differentiated in specific domain components which have their specific developments and declines (Dang, Braeken, Ferrer, & Liu, 2012).

Another possible explanation for the differential decline age- dependent could be related to differences in the previous experience processing verbal and visual-spatial materials. During the course of life usually people acquire greater expertise processing verbal material than visuo-spatial. Moreover, these differences in expertise could be exacerbated by the kind of tasks that are usually used in research on cognitive ageing. Jenkins and colleagues (2000) also considered the possibility that differences in the changes related to age in verbal and visuo-spatial neural substrates may explain the differential decline emerging in cognitive performance of elderly participants. For example, the larger decline in visuo-spatial working memory could be linked to a differential deterioration dependent by age in the neural systems, or it could reflect differences in the connection of the underlying verbal and visual-spatial neural networks. However, the authors report that none of the proposed mechanisms seem to adequately explain the pattern of results obtained from their research (Jenkins et al., 2000). In general, it seems that visuo-spatial working memory is particularly age-sensitive, compared to the verbal component (Bo, Jennett, & Seidler, 2012; Hale et al., 2011; Park et al., 2002; Jenkins, Myerson, Joerding, & Hale, 2000; Jenkins, Myerson, Hale, & Fry, 1999; Verhaeghen, Cerella, Semenec, Leo, Bopp, & Steitz, 2002; Bopp & Verhaeghen, 2007). In accordance with these observations, separable working memory subcomponents may have different age-related trajectories (Dang et al., 2012).

Recently, studies have investigated the difficulties that older people face in tests of visuo-spatial working memory which is an important construct as processing of visual-spatial material represents an extremely common experience in everyday life (eg, driving) (Thomas, Bonura, Taylor, & Brunyé, 2012). From these studies, age difference seems to be apparent in complex working memory tasks where information about object identity and localisation has to be linked together.

In contrast with the results in favour of an effect of age-specific in working memory previously described, other studies have reported conflicting data (Mammarella, Borella, Pastore, & Pazzaglia, 2013) or the opposite pattern of results (Fastenau, Denburg, & Abeles, 1996; Vecchi, Richardson, & Cavallini, 2005) showing *no difference between verbal and visual-spatial* tests (Borella, Ghisletta, & de Ribaupierre, 2011; Borella et al., 2008; Park et al., 2002; Salthouse, 1995; Shelton, Parson & Leber, 1982). Some studies (Hale et al., 2011; Park et al., 2002) suggest that there is not a considerable difference between decline in visuo-spatial and verbal memory processes across the life span for simple storage and complex span tasks (Borella et al., 2011). For example, Park and colleagues (2002) have administered a sample of adults, aged from 20 to 92 years old, to series of tests which measure processing speed, short-term memory, working memory and long-term memory. In an attempt to study the architecture of different memory systems and to analyse the interconnections through the life span. The authors found that there is a small difference between working memory decline in verbal and visuo-spatial across the lifespan. Moreover, it has been observed little evidence of a de-differentiation at the behavioural level in the elderly compared to young people (Park et al., 2002).

Kemps and Newson (2006) have speculated that these conflicting results could be, at least in part, attributable to methodological discrepancies between the studies in question, for example, the range of age or the tasks used to measure verbal and visual-spatial processes. The authors have highlighted how verbal and spatial tests used in this type of research often differ in terms of the paradigm used (Fastenau et al., 1996; Myerson et al., 1999; Park et al., 1996), familiarity of stimuli and for processing requests (Salthouse, 1995). Kemps and Newson (2006) emphasised the importance of using verbal and visual-spatial equivalent tasks in research on ageing. In their study, they adopted validated verbal and visuo-spatial memory tasks. Their results showed that (using equivalent tests), there is any differential decline in verbal and visual-spatial working memory. The authors concluded that the elderly have worse performance than young people in all complex span tests requiring attentional control, regardless of the type of material used (see de Ribaupierre & Lecerf, 2006; de Ribaupierre & Ludwig, 2003).

1.4.7 Changes with age in executive functions

Executive functions, defined as the set of mechanisms that modulate and regulate different cognitive processes (Miyake et al., 2000) (see chapter one) start to decline from around 50 years old (Charlton, Barrick, Markus & Morris, 2009). In recent years interest about the effects of age on executive functions has grown, since a lower efficiency of the executive processes involves a great impact on daily lives of the elderly. In the brain, the executive functions are mainly supported by the frontal lobes, specifically the prefrontal cortex (Jonides & Smith, 1999). Age-related changes in executive functions may, therefore, be explained by referring to the frontal lobe hypothesis of ageing (Dempster, 1992), that this brain region would be the first to experience an early involution with the advanced age.

After a long debate about the unity or diversity of executive functions, the classification in the literature includes at least three executive processes: inhibition, updating and shifting (Miyake et al., 2000). However, it still remains an open question about how the executive functions change with the progression of age. According to the hypothesis of dedifferentiation (Antsey, Hofer & Luszcz, 2003), with the progression of age there could be experience a process of unification of the executive functions. In an attempt to test this hypothesis, Hull, Martin, Beier, Lane and Hamilton (2008) administered to a sample of 100 participants from 51 to 74 years old a series of tests that measure inhibition, updating and shifting. Through a confirmatory factor analysis, the executive tasks loaded on two factors, updating and shifting, in the sample of older adults, highlighting the absence of the third factor detected in young adults, inhibition. The authors said, however, that their results are not consistent with the hypothesis of dedifferentiation; because this hypothesis would predict that a single factor can be able to describe most of the variability of the tests used. In conclusion, the results of this study showed that in normal ageing the dedifferentiation of executive functions do not exist, but rather their reduction. Similar findings are obtained by the study of De Frias, Dixon and Strauss (2009), which examines the structure of executive functions in three cognitively different groups of older people. The authors have distinguished among a group of cognitively strong older adults, a group of normal elderly and a group of cognitively impaired elderly people. The results showed that the first group of elderly had a structure of executive functions similar to young adults (De Frias et al., 2009).

1.4.8 Binding

The majority of research on binding in older adults is focused on deficits in episodic memory (Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003, 2004). A main researcher in this field has been Naveh-Benjamin (2000) who claims that older adults show difficulties to form and retrieve links between items. Naveh-Benjamin and Kilb (2014) suggested to explain age-related declines in older adults through the *associative-binding deficit hypothesis* (ADH, Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003). There are several studies which support this hypothesis that demonstrate that older adults show difficulty to retain the associations between different features, while they perform normally in memory for separate components (Naveh-Benjamin & Kilb, 2014). It has been noticed that older adults perform less accurate for associations between paired faces (Bastin & Van der Linden, 2005), pictures (Naveh-Benjamin et al., 2003), paired names and faces (James, Fogler, & Tauber, 2008), paired words (Castel & Craik, 2003; Healy, Light, & Chung, 2005), combining words and no words (Naveh-Benjamin, 2000), combining drawings and locations (Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000) and many other forms of pairing information. The main result of this theorisation is the observation of age-related binding deficit in long-term memory tests (Old & Naveh-Benjamin, 2008). Another interesting observation about older adults' associative deficit comes from the hypothesis that they may use inefficient strategy at encoding or retrieval. This problem then can be solved for example stimulating effective strategies among older adults (Naveh-Benjamin & Kilb, 2012; Naveh-Benjamin, Brav & Levi, 2007).

In addition to declines in verbal and visuo-spatial working memory, it has been suggested that memory for bindings between elements in memory may be particularly impaired in healthy ageing. For example, studies have shown that older adults are less accurate on tests of shape-location binding, relative to memory for individual elements (Borg et al., 2011; Chalfonte & Johnson, 1996; Mitchell et al., 2000; Thomas et al., 2012). This may be specific to tasks requiring binding to location, as other forms of binding (e.g., between shape and colour) do not consistently produce age-related declines (Allen, Brown, & Niven, 2013). Similar findings were obtained in a series of experiments carried out by Chalfonte and Johnson (1996) who found that older adults showed difficulties to recall features compared to younger adults, when it was asked to remember information about location. At the same time, it has been observed that older people performed poorly in tasks involving memory of object-location bindings. However, the authors (Chalfonte & Johnson, 1996) noticed that older people did not show impairments to remember single features (for example colour or object information separately), but age related binding deficit emerged when participants were asked to combine these features. For these experiments a grid with objects in pseudo-random locations was administered to older and younger adults, asking to remember the combination of features or one specified feature. A similar paradigm was used by Mitchell and colleagues (2000) exploring visuo-spatial binding tasks in working memory in older adults. Their results demonstrated a specific age-related binding deficit linked with impaired hippocampal functioning and right prefrontal cortex (Mitchell et al., 2000). The crucial role of the hippocampus in visuo-spatial binding in working memory has also been observed in other studies (Olson, Page, Moore, Chatterjee, & Verfaellie, 2006; Piekema, Kessels, Mars, Petersson, & Fernández, 2006; Jeneson & Squire, 2012) demonstrating its involvement in visuo-spatial binding processes (see e.g. Baddeley et al. 2010; Allen et al. 2014).

Age-related binding deficits in visuo-spatial working memory were also demonstrated by Cowan, Naveh-Benjamin, Kilb and Saults (2006) and Borg and colleagues (2011). However, this data seems to be limited as binding of surface visual features has been elusive. Indicating the importance of considering the involvement of location to remember as a relevant factor to take into account (Allen et al., 2013). In fact, a study conducted by Brockmole, Parra, Della Sala, and Logie (2008) found that the binding between visual features was not affected by age even though older adults compared to younger showed memory deficits overall (Parra, Abrahams, Logie, & Della Sala, 2009). Older people seem to show difficulty to learn combinations of features for longer-term memory compared to younger people (Logie et al., 2015), with a decline in learning and retaining new associations of information (Logie, Brockmole & Vandenbroucke, 2009; Kild & Naveh-Benjiamin, 2015).

These findings are linked with the observations that the ability to remember visual material, over a short period of time, decreases with the progression of age (Reuter-Lorenz & Sylvester, 2005). It has to be noted that not many studies investigated age-related decline in visual working memory (Brown & Brockmole, 2010) although older adults show severe deficits in visuo-spatial working memory (Jenkins et al., 2000; Leonards et al, 2002; Kemps and Newson, 2006; Park et al., 2002). It has been hypothesised that the decline in visual working memory is an age-related impairment in maintaining and binding the associations between items. Considering that objects are a combination of different visual characteristics, it is important to recall objects with the associated features, such as colour and shape. A deficit of age-related binding can explain the decrements recognised across the adult lifespan in visual working memory (Brown & Brockmole, 2010). Some studies showed deficits in object–location binding in older adults (Cowan, Naveh-Benjamin, Kilb, & Saults, 2006; Mitchell et al., 2000), while others found no difference across the adult lifespan in binding of the object's surface features (Brockmole, et al., 2008; Parra, Abrahams, Logie, & Della Sala, 2009). According to the hypotheses of binding deficit (Cowan et al., 2006; Mitchell et al., 2000), it has been claimed that this assumption can describe age-related declines in long-term memory (Naveh-Benjamin, 2000; Naveh- Benjamin, Guez, Kilb, & Reedy, 2004a; Naveh- Benjamin, Hussain, Guez, & Bar-On, 2003; Old & Naveh-Benjamin, 2008). In order to investigate binding on visual working memory in older adults Brown and Brockmole (2010) tested the effect of attentional load to see if age-related binding deficit could arise under the condition of executive resources limitation. In accordance with previous findings (Allen et al., 2006; Alvarez & Thompson, 2009; Logie, Brockmole & Vandenbroucke, 2009), the author reported results which show that binding objects is a fragile processes, susceptible to interference with no specific binding deficit in older adults. The age-related attention deficit (Craik, 1983; Hasher & Zacks, 1988) does not make worse deficits in visual working memory binding. These observations are also supported by Cowan and colleagues (2006) who claim that age-related visual working memory binding deficits exist beyond attentional limitation. In the second study carried out by Brown and Brockmole (2010) attention was manipulated and age-related binding deficit was found. It can be concluded that a small age-related visual working memory binding has been noticed (Brown, Niven, Logie, & Allen, 2012). In conclusion, it seems that "rather than an attention deficit, an impairment in associative processing or memory per se may underlie age-related visuo-spatial binding deficits in working memory, where they do exist" (Allen et al., 2015; pg. 90).

Finally, one study investigating binding of verbal and spatial information in older adults was conducted by Meier, Nair, Meyerand, Birn and Prabhakaran (2014) in order to explore the neural correlates of age-related differences. Participants were asked to bind letters and locations and it was found that the performance of older adults was not efficient as in younger adults. This was thought to be caused by the decline of cognitive control processes that are used in working memory binding (Meier et al., 2014). Despite the amount of data emerging from the literature on binding in older adults, verbal and spatial integration was not well investigated. The aim of the experimental study described in the experimental chapter was to systematically evaluate the phenomenon where verbal and spatial information are integrated, clarifying important theoretical issues around the functions and structures of working memory in older people.

1.4.9 Conclusions

There is now a broad consensus in the literature about age-related changes in the ability to perform many cognitive tasks (Craik & Salthouse, 2000). In recent years the number of studies and theories that have tried to explain the decay of some aspects of cognition in healthy elderly adults has significantly increased. The cognitive decline due to the progression of age could be explained with reference to some basic cognitive mechanisms, such as the information processing speed, the capacity of working memory, inhibition and sensory operation (Park, 2000). Given the complexity of human cognitive system, a reduction of its efficiency can be best explained by a combination of these mechanisms rather than from a single factor (Salthouse, 1991).

In particular, it has been suggested that working memory can be an important construct in order to understand cognitive aging as it is compromised in older adults (Babcock & Salthouse, 1990). Much evidence, in fact, has shown that elderly adults show lower performance than younger adults in working memory tests (De Beni et al., 2007; Robert et al., 2009; Vecchi et al., 2005). It has also demonstrated that working memory declines at different speed across the life span (Logie & Maylor, 2009) and it can be the main cause of higher order cognitive decline associated with normal aging (Verhaeghen & Salthouse, 1997).

In addition, a greater age-related decline in working memory tests which require a high executive control over the maintenance of passive information was confirmed (Bopp & Verhaeghen, 2005; Craik & Jennings, 1992; Vecchi & Cornoldi, 1999; Vecchi et al., 2005). As for the different subsystems of working memory, some studies have compared the effects of age in verbal and visual-spatial working memory tests, reporting mixed results. For example, Jenkins et al. (2000) found greater decline in visual-spatial than verbal processes. This pattern of results was confirmed by several other studies (Bopp & Verhaeghen, 2007; Myerson et al., 1999; 2003; Verhaeghen et al., 2002). On the contrary, Vecchi et al. (2005) found that older adults perform better in visual-spatial domain compared to verbal (Fastenau et al., 1996). According to other studies, however, there can be an equivalent decline in working memory, regardless of the type of material used (Borella et al., 2008; Park et al., 2002). Kemps and Newson (2006) have shown that using tasks with a similar or equivalent level of difficulty, but with different kinds of material, a similar decline in both verbal and visual-spatial working memory can be observed.

A few studies have investigated age-related deficits in working memory binding. The literature explored was focused more on visuo-spatial binding in older adults with contrasting results. Some studies show that older adults display deficits in object–location binding (Mitchell, et al., 2000), while others found no difference across the adult lifespan in binding of object's surface features (Brockmole, et al., 2008; Parra, Abrahams, Logie, & Della Sala, 2009). However, it has been shown that healthy adults are able to retain combination of colour and shape for few seconds, demonstrating that there is no additional effect of age holding features binding in working memory (Brockmole & Logie, 2013; Parra, Abrahams, Fabi, Logie, Luzzi, and Della Sala, 2009; Abrahams, Logie, & Della Sala, 2010a). This seems to be in contrast with age-related decline in visual short-term memory (Brockmole & Logie, 2013; Johnson, Logie & Brockmole, 2010). But healthy adults show no age-related decline to hold temporary feature binding in working memory. Moreover, older adults seem not to be as efficient as younger adults in verbal and spatial binding (Maier et al., 2014).

1.5. Working memory in Mild Cognitive Impairment's patients

This section examines working memory in people with Mild Cognitive Impairment. The diagnostic criteria, subtypes, the diagnostic scheme, therapy as well with the neuropsychology of Mild Cognitive Impairment with a specific focus on working memory are described. Study 3 is dedicated to the investigation of visuo-spatial bootstrapping in this population.

1.5.1 Mild Cognitive Impairment

1.5.1.1 Definition and Criteria

Mild Cognitive Impairment (MCI) is an evolving construct which refers to an intermediate and transitional state between normal cognitive changes due to ageing and late symptoms of dementia, such as Alzheimer's disease (AD) (Petersen, 2006, 2008, 2011). MCI is a clinical condition used as a description to identify patients at risk of developing AD in the pre-clinical stage (Allegri, Russo, Kremer, Taragano, Brusco, Ollari, Serrano, Sarasola, Demey, Arizaa & Bagnati, 2012), useful both clinically and in a research setting. In recent years, the literature on MCI has considerably increased (Petersen, Knopman, Boeve, Geda, Ivnik, Smith, et al., 2009). As a result, different diagnostic criteria for this condition have been proposed (Winblad, Palmer, Kivipelto, Jelic, Fratiglioni, Wahlund, et al., 2004); discussed later in this section. The construct of mild cognitive impairment is clinically relevant as it is used to describe earlier clinical signs of dementia and has become over the last fifteen years become a focus of clinical, neuroimaging, biomarker, epidemiological, neuropathological and clinical research trials (Petersen et al., 2009).

Since the the concept of "mild cognitive impairment" was first introduced in the literature with the terminology of Benign Senescent Forgetfulness (Kral, 1962), several different terms have been used to refer to the concept of "cognitive impairment, not yet dementia" such us: Age-Associated Memory Impairment (Crook, Bartus, & Ferris, 1986), Minimal Dementia (Roth, Tym et al., 1986), Limited Cognitive Disturbance (Gurland, Dean, et al. 1982), Questionable Dementia (Hughes, Berg et al., 1982; Morris, Edland,Clark, Galasko, Koss, Mohs, et al., 1993), Mild Cognitive Disorder (World Health

Organisation, 1993), Aging-Associated Cognitive Decline (Levy, 1994), Mild neurocognitive disorder (American Psychiatric Assoc, 1994), Cognitive impairment no Dementia (Ebly, Hogan, et al., 1995).

Mild Cognitive Impairment (MCI) was defined for the first time by Petersen et al. (1999). The **original criteria of Mild cognitive impairment by Petersen** (1999), are: (1) memory complaint, preferably qualified by an informant; (2) objective memory impairment for age; (3) preserved general cognitive function; (4) intact activities of daily living and (5) not demented. Petersen and colleagues (1999) focused on MCI as a prodromal condition for AD and therefore emphasised memory impairment in the criteria. However, not all forms of mild cognitive impairment progress to AD and in 2004 at the international conference on MCI, the criteria were expanded to include other forms of cognitive impairment. Established clinical consensus criteria according to the **Report of the International working group on Mild Cognitive Impairment (Winblad et al., 2004)** are:

1. Patient is not normal, but not demented (DSM-IV, APA, 2000)
2. Evidence of cognitive deterioration for age

   Objective measured decline over time in cognitive task performance, and/or

   subjective report of decline by patient and/or informant and objective cognitive deficits
3. Preserved activities of daily living and minimal to no impairment on complex instrumental functions

Despite these different criteria, the common theoretical groundwork on mild cognitive impairment, defined by the International Working Group on MCI, "(i) refers to non-demented persons with cognitive deficits measurable in some form or another, and (ii) represents a clinical syndrome that can be utilised to classify persons who do not fulfil a diagnosis of dementia, but who have a high risk of progressing to a dementia disorder" (Winblad et al., 2004, p. 241).

It has to be taken into account that, during the assessment of people with suspected mild cognitive impairment, both cognitive and functional abilities need to be examined, as functional activities should be mainly preserved in order for the condition to be categorised as MCI (Winblad et al., 2004). Moreover, patients should report cognitive decline referred by self or an informant (person with knowledge about the patient's cognitive functioning), in association with impairments assessed through neuropsychological tests.

Although individuals with mild cognitive impairment have a higher risk of progressing to dementia, some remain stable or return to a normal cognitive state (Winblad et al., 2004; Gauthier & Touchon, 2005; Gainotti, Quaranta,Vita, & Marra, 2013). The estimate of patients with MCI who develop AD annually varies from 10–15% (Grundman, Petersen, Ferris, Thomas, Aisen, Bennett, et al., 2004; Roach, 2005), but some progress to other forms of dementia such as Vascular dementia and dementia with Lewy bodies (Fischer, Jungwirth, Zehetmayer, Weissgram, Hoenigschnabl, Gelpi, & Tragl, 2007; Rountree, Waring, Chan, Lupo, Darby, & Doody 2007).

In the Mayo Clinic Study of Aging, prevalence of MCI is approximately 16% of elderly subjects free of dementia (Petersen et al., 2009). This is a population study involving a random sample of nearly 3000 participants, ages 70-89 years, who were cognitively normal or had MCI at entry. Amnestic MCI (aMCI) is the most common type of MCI with a high prevalence among men (Petersen et al., 2009; Ganguli, Dodge, Shen, & DeKosky, 2004). Amnestic MCI (aMCI) is one of the three clinical subtypes of classification of MCI: amnestic, single non memory domain and multiple cognitive domains slightly impaired.

The recently published revised criteria for MCI came from a group of experts convened by the **Institute on Aging and the Alzheimer's Association (NIA)** (Albert, DeKosky, Dickson, Dubois, Feldman, Fox, Gamst, Holtzman, Jagust, Petersen, Snyder, Carrillo, Thies, & Phelps, 2011). The workgroup defined two sets of criteria according to setting:

- *Core Clinical Criteria* used by healthcare professionals (without the use of imaging techniques or cerebrospinal fluid analysis). These have been defined in order to have clinical criteria that should be used ordinarily without highly specialised tests and methods in every different setting.
- *Clinical Research Criteria,* that can be used only in a clinical research setting, include the use of biomarkers based on imaging and cerebrospinal fluid measures.

The National Institute on Aging- Alzheimer's Association workgroups used the term "mild cognitive impairment (MCI) due to AD" talking about the symptomatic pre dementia phase of AD, considered as a subgroup of the different causes of cognitive difficulties that are not dementia, but could be consequences, for example, of metabolic disturbance, head trauma or substance abuse (Lyketsos, Colenda, Beck, Blank, Doraiswamy, & Kalunian, 2006). This kind of diagnostic category can be defined using clinical, functional and cognitive criteria, because it depends upon both the judgment of clinician and laboratory tests (Petersen, 2004).

Core clinical criteria

The National Institute on Aging- Alzheimer's Association workgroups indicate that it is difficult to separate normal cognition, mild cognitive impairment and dementia. It is ambitious to define them and clinical knowledge is essential to do it. The criteria for the clinical and cognitive syndrome are:

1) *change in cognition* compared to the previous level of patient, recognised by the affected individual, an informant who knows the patient or by a skilled clinician;
2) *objective impairment in one or more cognitive domains* over time (such as memory, attention, language, executive functions, visuospatial skills, etc..). It has been observed a lower performance in one or more cognitive functions than it can be expected from people with the same age and level of education.
3) *independence in functional activities*. People with MCI can perform complex functional tasks with mild difficulties, taking more time than in the past, less efficient and with some mistakes without any effect to their daily life.
4) *absence of dementia.* The cognitive difficulties should be mild and not severe, without evidence of relevant social and occupational impairment.

Research criteria with biomarkers

Biomarkers are used in clinical settings giving advantageous information about treatments and timing progression of dementia. Their different properties could benefit the research as well for the inclusion criteria of subjects. There are several classes of biomarkers. Beta-amyloid protein (Aβ) and tau are those which reflect the pathology of AD (Selkoe, 2005) with Aβ deposition in plaques and deposition of tau in neurofibrillary tangles. These combinations of biomarkers in the brain are associated with neuronal injury and are highly informative. Specifically, markers of Aβ deposition consist of positron-emission tomography (PET) evidence of Aβ deposition and cerebrospinal fluid (CSF). At the same time, markers of tau accumulation comprise cerebrospinal fluid measures of increased total tau or phosphorylated-tau (p-tau) (Shaw, Vanderstichele, Knapik-Czajka, Clark, Aisen, Petersen, et al., 2009). These two biomarkers in combination provide a high likelihood of progression to AD in patients with MCI.

In conclusion, the clinical research criteria defined biomarkers in terms of whether they reflect Aβ deposition, tau deposition, or signs of neuronal injury (Albert et al., 2011). In order to increase the predictive value of mild cognitive impairment, the analysis of molecular and structural neuroimaging and the cerebrospinal fluid (CSF) for amyloid β or tau proteins should be included in order to detect abnormal biomarkers. This information may be useful both for research and clinical purpose (Gainotti et al., 2013).

Another relevant definition of neurocognititive disorders, including MCI and Alzheimer's disease, come from the new edition of the **Diagnostic Manual of Mental Disorders** (5^{th} Edition, DSM-5, APA, 2013). According to the APA (American Psychiatric Association) with the new manual it has been replaced the term "dementia" with *major neurocognitive disorders* and *mild neurocognitive disorders* focusing on decline rather than deficits. One of the main reasons for this change of terminology is to reduce the stigma associated with the term dementia. Specifically, the second category is introduced for early detection and treatment of cognitive decline before patients' deficits become more marked and progress to major neurocognitive disorder. It could be desirable if early interventions may enable the use of treatments that are not effective at more severe stages of impairment and may slow progression.

The diagnostic distinction proposed by APA relies on clinician judgment and observable behaviours without an objective distinction (APA, 2013). With regards to these criteria, mild neurocognitive disorder goes beyond normal issues of ageing and requires "modest" cognitive decline which does not interfere with the independence of everyday activities, such as paying bills or taking medications, whereas the "major" criteria implies "significant" impairment. In this case, the difficulty should be evident or reported and it does interfere with a patient's independence. These differences from a normal cognitive performance are usually observed by a close relative, or other knowledgeable informant, such as a friend or clinician, or they are detected through objective testing.

Specifically, APA criteria (2013) for *mild neurocognitive disorders* are:

1. Evidence of modest cognitive decline from a previous level of performance in one or more cognitive domains — such as complex attention, executive function, learning, memory, language, perceptual-motor or social cognition.

This evidence should consist of: concerns of the individual, a knowledgeable informant (such as a friend or family member), or the clinician that there is a mild decline in cognitive function. At the same time there should be a modest impairment in cognitive performance, preferably documented by standardised neuropsychological testing. If neuropsychological testing is not available, another type of qualified assessment has to be administered.

2. The cognitive deficits do not interfere with capacity for independence in everyday activities (e.g., complex instrumental activities of daily living such as paying bills or managing medications are preserved, but greater effort, compensatory strategies, or accommodation may be required).

3. The cognitive deficits do not occur exclusively in context of a delirium, and are not better explained by another mental disorder.

1.5.1.2 MCI subtypes

Several clinical subtypes of mild cognitive impairment exist and they can be classified according to three groups: amnestic MCI (a MCI) if memory domain is impaired, multiple domain MCI (md-MCI) which involves various degrees of mild impairment in multiple cognitive domains such as executive function, language and visuospatial skills with a memory impairment (mdMCI + a) or without a memory impairment (mdMCI – a) (Petersen, 2003, 2004). The last one is the most common type of MCI, even if the most studied is the amnestic MCI (Petersen, 2004; Gangiuli, Dodge, Shen & DeKoskey, 2004). Patients with amnestic MCI show a conversion to AD per year of 6% to 15% (Fisk, Merry, & Rockwood, 2003; Daly, Zaitchick, Copeland, Schmahmann, Gunther, & Albert, 2000), while around 20% to 30% of them (aMCI) develop another type of dementia (Petersen et al., 2009).

All these MCI subtypes should also have mild difficulties in functional activities without a significant impairment in the daily life and a relevant change in function from a precedent level (Petersen, 2004). Neuropsychological assessments are necessary in order to define the specific clinical subtypes (Winblad et al., 2004) which have different aetiologies, causes and outcomes (Figure 10).

As it can be observed from the Figure 10, the combination of clinical subtypes and putative aetiologies can be useful in order to predict different form of dementias. The amnestic subtypes will likely progress to AD, both as a single domain impairment and as a multi domain (Petersen et al., 2004). The amnestic multiple domain mild cognitive impairment can also likely represent a prodromal form of Vascular Dementia (VaD). Alternatively, the non-amnesic MCI subtypes (which emphasise impairments in non-memory domains such as language and executive function) may have a higher likelihood of progressing to Fronto Temporal Dementia (FTD), Lewy Body Dementia (DLB) and Vascular Dementia (VaD) (Boeve, Ferman, Smith, et al., 2004).

Figure 10. Presumed outcome of the different subtypes of mild cognitive impairment (MCI) connected with the supposed pathogenesis (Petersen 2003; 2009).

Etiology

Clinical Classification		Degen-erative	Vascular	Psychiatric	Medical Conditions
Amnestic MCI	Single Domain	Alzheimer's disease		Depression	
	Multiple Domain	Alzheimer's disease	Vascular dementia	Depression	
Non-Amnestic MCI	Single Domain	Fronto Temporal Dementia			
	Multiple Domain	Dementia with Lewy bodies	Vascular dementia		

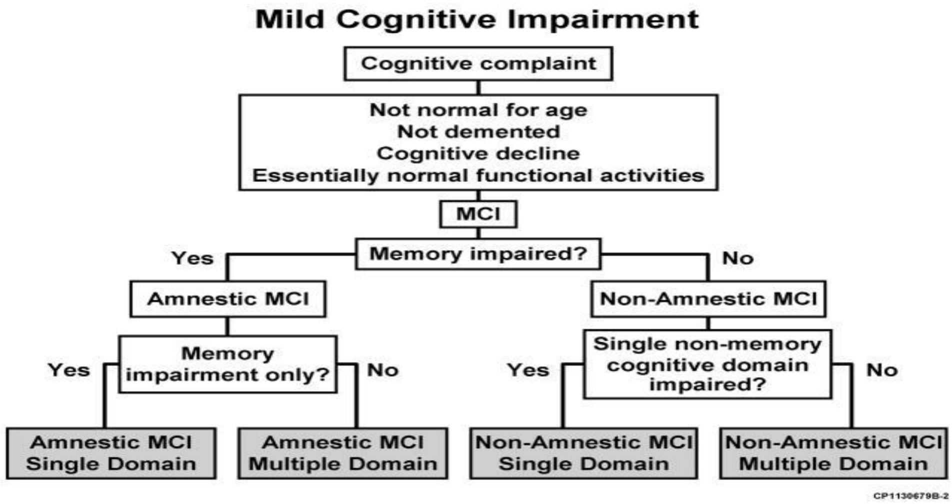
1.5.1.3 Diagnostic scheme

According to the diagnostic scheme proposed by Petersen (2004), useful procedure to make a diagnosis of MCI might follow the suggestions of the flow chart in Figure 11.

In general, the diagnostic process starts from complaints about the cognitive difficulties faced by patients directly or a family member. This concern should be carefully taken into account by doctors because it could be an initial sign of dementia as well as a depression. The judgment of the clinician has to be done according to the history and a mental status examination of the person in order to define the cognitive level as normal or suspected dementia. For instance, there could be cases where the person displays a low score on a screening test like Mini Mental Mental Status Examination (MMSE; Folstain et al., 1974) and consistent impairments in functional activities. This can be a clear case of a diagnosis of dementia. On the contrary, despite subjective concerns about cognitive performances, a person could be classified as normal (or in other cases depressed) because the score on the MMSE is high and there are not difficulties in activities of daily living. When a subject cannot be classified as normal or demented, but shows cognitive difficulties, a diagnosis of MCI is applied, after an extensive neuropsychological examination and interviews with the patients and an informant. Assessing all the cognitive functions like memory, language, attention, executive function or visuospatial skills, the clinician can understand if the person can be classified as an amnestic MCI or non-amnestic. The following step is to determine if there are multiple or single domain of impairment. The meaning of this classification is to establish the final outcome of these different subtypes of MCI (Petersen, 2004).

Turning to a more general examination made by neurologist, an assessment,which also includes the examination for the presence of potential causative co morbid conditions and the evaluation for the presence of sensory and/or motor deficits as potential causes or exacerbating factors, needs to be done. Moreover, computed tomography (CT) or brain imaging with magnetic resonance imaging (MRI) is often performed in patients with MCI in order to predict progression from MCI to AD (Risacher, Saykin, West, Shen, Firpi & McDonald, 2009).

Figure 11. Flowchart for the diagnosis of MCI and its subtypes (Ritchie et al., 2000 in Petersen, 2004).



1.5.1.4 Prognosis

There are four different subtypes of mild cognitive impairment (Petersen 2003, 2004) which progress to AD at different rates, experiencing progressive deterioration in their abilities to perform activities of daily living, cognition, and behaviour. Generally, for all mild cognitive impairment subtypes, the conversion rate to dementia is 56% (14% annually) during four years, and the percentage of patients with mild cognitive impairment who will develop AD is around 46% (11% annually). It has been observed that the conversion rate to AD for amnestic MCI was 56%, 50% for amnestic-subthreshold MCI, and 52% for non-amnestic MCI (Rountree, Waring, Chan, Lupo, Darby, & Doody, 2007). With regard to healthy elderly individuals the percentage of them who develop AD is 1-2% per year.

Patients with MCI are seven times more likely to develop AD than older people without cognitive impairment (Boyle, Wilson, Aggarwal, Tanq, & Bennet, 2006) and 80% of them will progress to dementia after 6 year. MCI has been identified as an independent predictor of mortality (Sachs, Carter, Holtz, Smith, Stump, Tu, & Callahan, 2011;

Winblad et al., 2004) with the risk of death increased about 50% among both African American and white patients (Wilson, Aggarwal, Barnes, Bienias, Mendes de Leon, & Evans, 2009). Talking about the progression of mild cognitive impairment, the single-domain amnestic MCI profile is correlated with the highest risk of conversion to AD. This is also the case when memory impairments did not go over specific cut-off points. This observation is also sustained by biomarker analyses (Damian, Hausner, Jekel, Richter, Froelich, Almkvist, et al., 2013).

1.5.1.5 Therapy

To date, there are no efficient treatments for MCI and AD (Ritchie & Tokko, 2010; Callaway, 2012). For this reason, it is important to take care of different steps that could be from a primary care level to pharmaceutical interventions with patients with mild cognitive impairment.

In the first level of intervention, general practitioners should be involved to take notes of cognitive history verifying possible deterioration and the presence of subjective cognitive complaints. This practice can identify possible treatable causes of cognitive impairment such as medication side-effects, cerebrovascular risk factors (e.g. diabetes, hypercholesterolaemia and high blood pressure), vitamin deficiency (e.g. B12 and folate), somatic illness and psychiatric illness (e.g. depression) especially with periodical follow up. When cognitive difficulties progress over the time, patients should be visited by specialists such as neurologists and neuropsychologists who should investigate the progression of the difficulties. Moreover, investigations with neuroimaging techniques (Magnetic Resonance Imaging- MRI, Single-Photon Emission Computed Tomography-SPECT and Computed Tomography- CT) and possible CerebroSpinal Fluid - CSF biomarkers and Positron Emission Tomography – PET, should be used as an essential part of the evaluation of MCI subjects in order to make a complete clinical judgement. Brain imaging is an essential part of the assessment because it can contribute to extra diagnostic information; for example to identify distinct causes of cognitive decline (i.e. brain tumour and subdural haematoma) and to define differential diagnoses. In addition, it can be used for predicting the possibility of developing dementia and measuring its progression (Winblad et al., 2004). The MRI has been shown to predict progression from MCI to AD through the volume of the whole brain and hippocampal (Risacher et al.,

2009) as well as has apolipoprotein E (ApoE) status (Boyle, Buchman, Wilson, Kelly, & Bennett, 2010).

With regards to possible *interventions* to adopt, there are some studies which show that cognitive interventions may have a positive effect with patients with MCI and their families (Kinsella, Mullaly, Rand, Ong, Burton, Price, et al., 2009; Simon, Yokomizo, & Bottino, 2012). Through a meta-analysis of 19 studies, it has been observed the importance of cognitive intervention in improving cognitive and functional abilities (Sitzer, Twamley & Jeste, 2006). Generally, at the primary care level, intervention should focus on primary prevention of modifiable risk factors for cognitive impairment, while medical care actions should target on exclusion of treatable causes of them. Treatment of behavioural and psychiatric symptoms and longitudinal assessments are desirable working with people with MCI (Winblad et al., 2004).

It has been demonstrated that amnestic MCI patients can benefit from cognitive interventions because they are still able to use different strategies to learn new information, such as visual imagery, external aids and spaced retrieval (Simon et al., 2012). The effects of these interventions have a variable duration depending on specific studies and combination of techniques, from some months up to two years following an intervention (Belleville, Gilbert, Fontaine, Gagnon, Menard, & Gauthier, 2006; Londos, Boschian, Linden, Persson, Minthon, & Lexell, 2008; Unverzagt, Kasten, Johnson, Rebok, Marsiske, Koepke, et al., 2007). Little evidence has been reported for computerised cognitive training both in patients with mild cognitive impairment (Clare, Woods, Moniz Cook, Orrell, & Spector, 2003) and in healthy older subjects (Owen, Hampshire, Grahn, Stenton, Dajani, Burns, Howard, & Ballard, 2010). On the contrary, group interventions seem to be an effective option in patients with MCI due to better cost-benefit than individual therapeutic approaches. An additional advantage of group-based interventions is the element of social interaction, a factor that seems to prevent cognitive decline in older people (Fratiglioni, Paillard-Borg, & Winblad, 2004) and MCI patients (Petersen, 2011).

To date, *pharmacological treatment* for MCI and dementia seem to have only moderate effects on behaviour, cognition and function. One of the reasons is that there are no randomised controlled clinical trials supporting evidence that medications used for

dementia could have effect with MCI patients (Winblad et al., 2004). Specifically, donepezil hydrochloride (one of the most common trade name is Aricept) seems to delay the progression to AD in MCI. In 2011 the National Health Service's National Institute for Health and Care Excellence (NICE) recommended it for mild and moderate AD (NICE, 2011). However, the effect of donepezil on cognition has been found in industry-funded research rather than independent studies (Killin, Russ, Starr, Abrahams, & Della Sala, 2014). It has been noticed that NICE took that decision based on two meta-analyses of randomised controlled trials (RCTs) that demonstrated the positive effect of donepezil on behaviour, function and cognition (Bond, Rogers, Peters, et al., 2012). Nevertheless, 12 studies on 19 used as clinical trials were produced by the companies that manufacture and advertise donepezil that are more likely to find preferential outcomes for the industry's product (Lundh, Lexchin, Sismondo, et al., 2012; Tungaraza & Poole, 2007).
On the other hand, cholinesterase inhibitors also appears to have no effect to delay the onset of AD or dementia in MCI (Panza, Frisardi, Capurso, D'Introno, Colacicco, Chiloiro, Dellegrazie, Di Palo, Capurso, & Solfrizzi, 2010).

All the interventions described above need to be interpreted with caution. In studies with MCI patients there are several methodological limitations such as small sample size, variety of instruments and techniques used and non-controlled experimental designs (see systematic review Simon et al., 2012).

1.5.2 Neuropsychology of mild cognitive impairment

Neuropsychological assessment is an essential examination part of the broad neurological evaluation that allows to observe the status of a patient's health, identifying the impaired cognitive functions. It contributes to the diagnosis of neurological diseases, even when the neuroradiological tools do not show abnormalities (Mondini, Mapelli, Vestri, Arcara, & Bisiacchi, 2011). Generally, neuropsychological evaluations can contribute to define severity and type of cognitive impairment, distinguish dementia from pseudo dementia and make differential diagnosis. Furthermore, it can be effective to identify patients' needs for adaptation to a new condition, establishes possible risks to live alone and make decisions for instance. At the same time, it may evaluate the effectiveness of therapies and to track progression of disease.

Neuropsychological assessment is essential in identifying patients with MCI who go on to develop dementia (Larrea, Fisk, Graham & Stadnyk, 2000; Gagnon & Bellville, 2011). Specifically, under investigation are not only the memory functions, but also other cognitive functions, such as language, attention, praxis, visual-spatial functions, executive function. Early detection of MCI may enable patients to benefit from interventions that could potentially slow down the course of the disease. However, there is not a standardised neuropsychological battery assessing for MCI (Ritchie & Tokko, 2010). To date, the guidelines (not cut off scores) indicate that tests for MCI patients are usually 1 to 1.5 standard deviations below the mean compared to matched controls on age and education level (Albert et al., 2011). Even if there is a strong emphasis on memory assessment for people at risk of developing dementia (Petersen et al. 2001), it should be taken into account that around 20% of cognitively impaired patients can be excluded from amnestic MCI categorisation when only verbal memory tests are used. It is also important to note that multi-domain MCI is more frequent in individuals who show both visual and verbal deficits (Alladi et al., 2006). It is clear that it is not possible to use merely a test to asses memory functionality, because "test performance may be influenced by psychiatric and neurological conditions, or normal fluctuations in individual performance" (Ritchie & Tokko, 2010, p. 5). For this reason, repeated neuropsychological assessment of all the cognitive functions is strongly suggested (Collie, Maruff, Shariq-Antonacci, Smith, Hallup, Schofield, et al., 2001) along with informants' interviews (Morris & Storandt, 2006).

It has been suggested that the assessment should be comparable to that of diagnosing dementia, which includes: history-taking, diagnostic testing and objective cognitive assessment (Chertkow, Massoud, Nasreddine, Belleville, Joanette, Bocti, et al., 2008). Moreover, it is relevant to ask about the impact on daily life both for patients and family members asking which cognitive functions may have changed over time. This is one of the most specific aspects of history-taking, since the degree to which functional abilities are preserved or impaired is what distinguishes MCI from dementia. In general, as it was already explained above, in MCI, basic ADL- Activity of Daily Living (grooming, feeding for instance) should be preserved and IADL- Instrumental Activity of Daily Living (e.g. cooking, finances) should be only minimally impaired. Patients can show slight changes in instrumental, but not basic, ADL - Activity of Daily Living (Pérès, Chrysostome, Fabrigoule, et al., 2006). In particular, it has been observed that functional abilities are associated with WM in all MCI subtypes (Aretouli & Brandt, 2010). Other aspects to take into account are all the information about the medical condition of the patient, including: psychiatric and medical disorders, current medications that can cause cognitive side-effects and family history of dementia. Moving to laboratory tests, these should include, among others, blood count, thyroid stimulating hormone, electrolytes, calcium, fasting glucose and vitamin B12 (Chertkow et al., 2008).

1.5.3 Memory in Mild Cognitive Impairment

Patients with severe memory impairment are more likely to progress from MCI to Alzheimer's than those who have a slight memory deficit, specifically amnestic MCI may be at increased rate of cognitive impairments compared to those with other MCI subtypes (Klekociuk & Summers, 2014). Even more specifically, MCI amnesic multi domain is a reliable precursor to development of Alzheimer's dementia (Gainotti et al., 2013; Petersen, 2008), even if the existing criteria for the subtypes of MCI show a remarkable instability in classification over time (Summers & Saunders, 2012). From a neuropsychological point of view, some authors claim that a reliable marker of progression of MCI into AD is the number of memory tasks compromised, in particular episodic memory tests (Albert et al., 2011; Harel, Daeby, Pietrzak, Ellis, Snyder & Maruff, 2011), primarily in the verbal and auditory-verbal modality (Salmon & Bondi, 2009) and semantic memory task (Gainotti et al., 2013). A number of studies have indicated episodic memory as a main domain of impairments in MCI, using paragraph recall, word lists, semantic cues and free recall of list of words (Kluger, Ferris, Golomb, Mittelman, & Reisberg, 1999; Tierney et al., 1996; Petersen et al., 1997; Jack, Petersen, Xu, O'Brien, Smith, Ivnik, et al., 1999). At the same time, the presence of preserved memory test performance may predict a return to normality of MCI patients. It has been noticed that it is not only the number of tasks compromised that predicts the conversion of MCI into dementia, but also the severity of deficit (Belleville et al., 2007) or measures of delayed recall (Gainotti et al., 2013). In fact, there are several tests which assess both immediate and delayed recall in order to verify retention over a delay (Albert et al., 2011), such as the Rey Auditory Verbal Learning Test (Rey, 1958). In order to increase the specificity of these predictors, it has been suggested for instance that stringent cut-off points are necessary (Gainotti et al., 2013). However, the sensitivity of tests assessing memory verbal paired associate learning, paragraph recall and verbal list learning in MCI is well established (Belleville, Sylvain-Roy, de Boysson, & Menard, 2008). All these studies are consistent with the focus on memory impairment made by Petersen (2003) who points out, in his MCI's criteria, the role of episodic impairment as the first domain of impairment in amnestic MCI progressing to AD (Belleville et al., 2007). On the other hand, there is evidence supporting that difficulties in visual paired associate learning could be observed in patients with risk to develop dementia like AD (Mitchell, Arnold, Dawson, Nestor, & Hodges, 2009; Ahmed, Mitchell, Arnold, Nestor, & Hodges, 2008; Maruff, Darby, Weaver-Cargin, Masters, & Currie, 2004; Blackwell, Sahakian, Vesey, Semple, Robbins, & Hodges, 2004). For this task, subjects are asked to associate simple patterns and spatial localisations through repeated exposure to the associations (Harel et al., 2011). It has been observed that patients with amnestic MCI compared to age-matched controls have a poorer performance in associating large sets of pattern-location (Mitchell et al., 2009). Moreover, several studies also seem to suggest that executive functions and attention may be impaired in MCI (Belleville et al., 2007; Perry & Hodges, 1999) as well as working memory, especially in tests involving divided attention and capacity of manipulation (Baddeley et al., 1991; Belleville, Rouleau, Van der Linden & Collette, 2003; Morris, 1986). Belleville et al. (2007) reported that not only the episodic memory impairment is involved in the evolution process from MCI to AD, but also attentional control could be damaged in this phase.

1.5.4 Working memory and Mild Cognitive Impairment

Several studies show that MCI is associated with a stable pattern of specific deficits to working memory, language (fluency, naming, comprehension, expressive speech), attention (divided and sustained attention), visual-spatial functions and executive function (planning, set-shifting, problem-solving, reasoning) (Saunders & Summers, 2010, 2011, 2012; Belleville, Chertkow, & Gauthier, 2007; Albert et al., 2011; Brant, Gardiner, Vargha-Khadem, Baddeley, & Mishkin, 2009; Espinosa, Alegret, Boada, Vinyes, Valero, Martınez- Lage, & Tarraga, 2009; Nordlund et al., 2005).

Working memory declines in dementia and in patients with mild cognitive impairment (Klekociuk & Summers, 2014; Cheng, Cai, Wang, Li, & Zhou, 2008; Saunders & Summers, 2011; Belleville et al., 2011; Lopez, 2005), with a progressive working memory impairment from healthy ageing to degenerative disease (Belleville et al., 2007; Gagnon & Belleville, 2011). This decline can have wide-reaching effects on many higher-level cognitive functions that rely on the more fundamental working memory processes. It has been found that working memory, as well as planning and problem solving, is particularly impaired in mild cognitive impairment patients. Compared with cognitively normal older adults, especially in subjects with multiple-domain mild cognitive impairment who have a highest risk of developing dementia (Brant et al., 2009).

Previous functional imaging research has reported a mixed pattern of memory-related neural activity differences between mild cognitive impairment and healthy controls. In the functional imaging study of working memory (Yetkin, Rosenberg, Weiner, Purdy, & Cullum, 2006) significantly increased activity was observed in the frontal cortex in mild cognitive impairment relative to healthy controls. Moreover, functional brain imaging studies revealed evidence of alterations in the frontal and temporal cortices associated with processing working memory tasks in mild cognitive impairment patients (Wang, Guo, Zhao & Hong, 2012; Niu, Li, Chen, Ma, Zhang, & Zhang, 2013). Compared to healthy elderly, mild cognitive impairment patients had a higher level of atrophy in frontal and medio-temporal regions and a different pattern of correlation between grey matter values and visuo-spatial performance. These observations correlate with visuo-spatial impairment and support the use of visuo-spatial memory tests as valid tools for assessment of mild cognitive impairment (Mitolo, Gardini, Fasano, Crisi, Pelosi, Pazzaglia, & Caffarra, 2013).

In the screening assessment to detect mild cognitive impairment patients, working memory has a relevant role because it has been observed that they show a reduced maintenance of bound information, i.e., object-location associations (Kessel, Meulenbroek, Fernandez, Rikkert, & Olde, 2010, Germano, Kinsella, Storey, Ong, & Ames, 2008) and for the impact that it can have in everyday functioning. The temporary and active retention of information on working memory is involved in several daily multi step tasks according to Humphrey and colleagues (2001). Those comprise, among others, representation of goals and stimuli and appropriate response to the environment (Baddeley et al., 2001), a damage of these processes can cause troubles completing tasks (Kimberg & Farah, 1993). Aretouli and Brandt (2010) suggested that impaired working memory can affect daily activities maintaining temporal characteristics of a script, supervising conflicts of sequence of actions and inhibiting irrelevant stimuli (Zanini, Rumiati, & Shallice, 2002; Sirigu, Zalla, & Pillon et al., 1996; Shallice & Burgess, 1996). Keeping track of conversations, packing or talking and walking at the same time (Alberoni, Baddeley, Della Sala, Logie, & Spinnler, 1992; Ramsden, Kinsella, Ong, & Storey, 2008; Camicioli, Howieson, Lehman & Kaye, 1997) could be affected as a consequence of working memory impairment. These findings could help to understand both cognitive and functional problems faced by mild cognitive impairment patients and early AD patients and support the identification of the working memory impaired process. This might also help to develop possible solutions to support this group of patients who experience difficulties in dividing attention and manipulating information (Huntley & Howard, 2009).

The functional status of working memory within mild cognitive impairment subtypes shows that the amnestic MCI patients perform poorly on all working memory tasks and in attention's tests, supporting previous studies which suggest amnestic MCI as an early stage of Alzheimer's disease (Dubois & Albert, 2004; Morris, 2006). Both working memory and attention may have a consistent role in understanding the transitional phase from MCI to dementia, because there has been evidence which suggest that they could anticipate episodic memory impairment in AD (Storandt, 2008; Grober, Hall, Lipton, Zonderman, Resnick, & Kawas, 2008; Rapp & Reischies, 2005) .

In a recent study conducted by Logie, Parra and Della Sala (2015) emerged a crucial role of temporal binding which seems to be specific in early stages of Alzheimer's disease. Patients in the early stages of AD experience specific deficits in this online cognitive process which involves binding different aspects of a stimulus on a temporary basis to create an integrate object by keeping track of changes in the environment (Allen et al., 2006; Logie & Van der Meulen, 2009). Temporary binding deficit is specific of early stages of Alzheimer's disease and is not found in healthy older adults (Parra, Abrahams, Logie, & Della Sala, 2009; Parra, Della Sala, Logie, & Abrahams, 2009). Patients tend to have a poorer performance in tasks which require to temporary retain shapes and colours in comparison with tasks in which there is a single feature (shape or colour). This task has been demonstrated to be able to discriminate between patients with Alzheimer's disease, chronic depression and other forms of dementia (Logie et al., 2015). For those reasons, temporary binding has been suggested to be a potential tool for the screening of Alzheimer's disease.

A different perspective is offered by Race, Palombo, Cadden, Burke and Verfaellie, (2015) in their study on memory integration in amnesic patients using visuo-spatial bootstrapping paradigm (Darling & Havelka, 2010). Participants were asked to remember random sequences of digits using familiar visuo-spatial display such as a typical keypad and unfamiliar visuo-spatial array of digits. In their study they found that the capacity to integrate verbal information with stored visuo-spatial knowledge appears to be preserved in both amnesic patients and controls. The authors (Race et al., 2015) concluded that long-term semantic knowledge can provide a mental scaffold to remember short-term information.

It has been observed that both amnestic MCI and non-amnestic MCI display a remarkable impairment to spatial working memory, visual spatial span and complex sustained attention (Summers & Saunders, 2011; Klekociuk & Summers, 2014). In addition, impairments to the central executive (CE) of working memory were noticeable in both groups showing difficulties in rule acquisition, complications with strategy use and attentional shifting (Summers & Saunders, 2011). Brant and colleagues (2009) underline how decline in central executive can be a risk factor to develop dementia according to Baddeley and colleagues (1991; 1986) because it predicts the onset of language and spatial impairments as well as it follows the beginning of episode memory problems in Alzheimer's disease (Bondi et al., 2002; Binetti et al., 1996). Moreover, several studies show that best cognitive tests used as screening tests for predicting dementia in a non-demented person, involved executive control resources (Albert, Blacker, Moss, Tanzi, & McArdle, 2007; Albert, Moss, Tanzi, & Jones, 2001; Rapp & Reischies, 2005; Elias, Beiser, Wolfe, Au, White, & D'Agostino, 2000).

In relation to neuropsychological tests used in the assessment of mild cognitive impairment, a body of evidence shows that Digit span seems to be preserved in mild cognitive impairment reflecting a normal functioning of short-term memory, which become impaired across mild and moderate groups (Orsini, Trojano, Chiacchio, & Grossi, 1988; Corkin, 1982; Greene, Hodges, & Baddeley, 1995; Huntley & Howard, 2009). The same is true for the Corsi Block Tapping test, used a measure of spatial memory span. It seems to be preserved in MCI, but impairments have been found in mild and moderate AD (Spinnler, Della Sala, Bandera, & Baddeley, 1988; Sahgal, Lloyd, Wray, et al., 1992; Grossi, Becker, Smith, & Trojano, 1993). The Corsi test involves visuo-spatial storage and executive processing that may be impaired in patients with AD (Carlesimo, Fadda, Lorusso, & Caltagirone, 1994), where phonological loop is preserved in mild AD (Peters et al., 2007) and becomes impaired when the disease progress to the mild to moderate stage (Huntley & Howard, 2009).

The component of forgetting should also be taken into account as a hallmark of AD because it could contribute to understand working memory deficits in MCI (Gagnon & Belleville, 2011; Hitch, Towse, & Hutton, 2001). The role of forgetting in working memory has been shown in complex span tasks through the manipulation in the lengths of the first and last trial items with difference in retention interval, or duration of storage. Older adults, patients with MCI and AD were sensitive to the interval length manipulation and to the order effect of complex span task. All groups showed difficulties when the duration of retention was incremented by the last long item. In this study the order effect was confirmed in all three groups (Gagnon & Belleville, 2011) which is the most commonly used measures of working memory capacity in clinical assessment (Conway, Kane, Bunting, Hambrick, Wilhelm & Engle, 2005). As it has been observed, the control component involved in complex span tasks can be a solid predictors of higher-order cognitive functions (Engle & Kane, 2004) and general fluid intelligence (Engle, 2001). Complex span task requires short-term storage and concurrent processing involved in working memory and it can be a valid tool to distinguish patients with MCI to healthy ageing according to Gagnon and Belleville (2011).

All the consideration made so far on the neuropsychological working memory profile of mild cognitive impairment should take into account the high degree of instability in mild cognitive impairment classification which could mask differences of impairments (Summers & Saunders, 2012; Han & Kim, 2012). Healthy older people can perform within a sub clinically impaired population and on the contrary, there is an high proportion of subjects who receive a diagnosis of mild cognitive impairment that revert to a normal levels of functioning at follow-up (Brooks, Iverson, Holdnack, & Feldman, 2008; de Rotrou, Wenisch, Chausson, Dray, Faucounau & Rigaud, 2005).

1.6. Introduction to the experimental chapters

The aim of the research presented in this thesis was to carry out a series of three experiments to investigate visuo-spatial bootstrapping through the examination of the contribution of subcomponents of working memory in visuo-spatial bootstrapping across the lifespan and in a sample of individuals presenting with initial symptoms of memory impairments. Specifically, this thesis aimed to determine the contribution of the central executive and the implication in younger and older adults and patients with mild cognitive impairment of visuo-spatial bootstrapping paradigm (Darling & Havelka, 2010; Darling et al., 2012, 2014; Allen et al., 2015).

In this chapter the theories that constitute the basis of the experimental studies are have been described. Initially, First of all, different models of working memory with a specific focus on the Multi Component Model (Baddeley & Hitch, 1974; Baddeley et al., 2011) are have been illustrated. According to this model, working memory is composed by the central executive and two slave systems, the phonological loop and the visuo-spatial sketchpad, which are passive stores that maintain information over short period of time. Slave systems are thought to be distinct from each other with good evidence supporting their segregation (e.g. Smith et al., 1996; Baddeley, Lewis & Vallar, 1984; Quinn & McConnell, 1996). However, when a stimulus fall in both domains, it needs to be encoded in both subsystems, but also link them together. In order to account for these processes, Baddeley (2000) proposed a new component of working memory, the episodic buffer. This limited capacity store is assumed to be recruited when information from different sources, including the working memory that subsystems, and long-term memory has to be bound together and temporarily retained (e.g. Allen, Baddeley, & Hitch, 2006; Allen, Hitch, & Baddeley, 2009; Baddeley, Hitch, & Allen, 2009; Bao, Li & Zhang, 2007; Karlsen, Allen, Baddeley, & Hitch, 2010). Visuo-spatial bootstrapping paradigm supports the most recent version of the multi component working memory model (Baddeley, Allen, & Hitch, 2011), which postulates that several different forms of binding information, such as visual, verbal and cross modal, can be automatically processed (Allen et al., 2006, 2014; Allen, Hitch, Mate, & Baddeley, 2012; Baddeley, Hitch, & Allen, 2009). Studies on visuo-spatial bootstrapping provide new insights for models of working memory and in particular for the multi component model by Baddeley (2000, 2007). The visuo-spatial bootstrapping effect seems to support the role of the episodic buffer within the model of working memory by Baddeley (2000, 2007). This effect can be served by the episodic buffer which was described as a component that connects modality-specific components (visuo-spatial and verbal), central executive and long-term memory.

The other theoretical sections illustrated in more details executive functions, binding processes and working memory in older adults and in patients with mild cognitive impairments.

The section on binding processes described the context in which the visuo-spatial bootstrapping paradigm has been developed. Four previous studies using visuo-spatial bootstrapping were described. This is a recent line of investigation concerned verbal and visuo-spatial information can be used to boost memory performance, demonstrating the presence of implicit cross-modality feature binding. This paradigm has been adopted differently according with their specific aims in the three studies according to the specific aims. It has been observed that verbal recall of the digit sequences is more accurate when these are presented within a familiar keypad array rather than single spatial location. Previous studies demonstrated that implicit bindings of visuo-spatial information and verbal information seems to facilitate performance in young adults (Darling et al., 2010, 2012) and children (Darling et al., 2014). It seems to support recall of verbal information only when subjects have previous knowledge of such associations. The experimental programme (divided in three different studies) was designed to investigate understand the role of central executive in the bootstrapping effect and how this effect affects working memory across the lifespan and in patients with early symptoms of memory difficulties.

The sections on executive functions and working memory in older adults and in patients with mild cognitive impairments constitute the literature framework and the theoretical background on which the three experiments have been based.

In section two on executive functions (chapter one) considerable attention is given to the central executive. This is one of the main components of the working memory model (Baddeley, Allen & Hitch, 2010) and the cognitive structure often associated with executive functions (Baddeley, 1986). The aim of the first study was to use the visuo-spatial bootstrapping paradigm to examine the contribution of subcomponents of working memory with a specific focus on the role of the central executive system. A dual-task paradigm was used and visuo-spatial bootstrapping was expected to be selectively impaired by concurrent tasks, such as articulatory suppression and central executive load. A possible outcome would be no visuo-spatial bootstrapping effect with central executive suppression affecting both display conditions (typical keypad and single digit display). Conversely, a visuo-spatial bootstrapping effect under central executive load could be predicted considering that this effect works implicitely and could potentially automatic. In support of this perspective there are several studies which describe a lack of attention in cross-domain binding (Prabhakaran et al., 2000; Langerock et al., 2014).

The other topic covered by the literature review is working memory in older adults with a specific focus on the differential decline in verbal and visual-spatial working memory and binding processes. Data emerged from previous studies (Darling & Havelka, 2010; Darling et al., 2012, 2014; Allen et al., 2015) demonstrating that visuo-spatial bootstrapping requires access to relevant long-term memory representations. This persists under phonological loop suppression but it is removed under visuo-spatial load, and it is not observed in six year old but it is present in nine year olds, and adults. The aim of the second study was to investigate visuo-spatial bootstrapping in a sample of older adults to explore the consistency of the effect across the lifespan. Elderly subjects represent a population that show cognitive decline in many cognitive functions (Manan et al., 2013) including working memory. Many studies observed that working memory declines with age (Jost et al., 2011; Myerson et al., 2003; Chen et al., 2003) and specifically binding appears to be impaired in healthy aging (Brockmole et al., 2008; Cowan et al., 2006; Maier et al., 2014; Mitchell et al., 2000; Parra et al., 2009). Taking into account the data emerging from literary sources; the central reason to investigate visuo-spatial bootstrapping in older adults was to explore this paradigm across the lifespan in order to to add beneficial data in the age-related research field. No bootstrappieng effect was expected to be found considering the literature on binding and ageing which indicates that older adults show difficulties in binding different features (Naveh-Benjamin & Kilb, 2014; Meier et al., 2014). On the other hand, if a visuo-spatial bootstrapping effect will be found, this will provide a theoretical basis for developing techniques to support older people to remain independent in their daily life for longer. It becomes necessary to develop translational research with an increasing number of older adults, in order to apply findings from cognitive studies on ageing to innovation on cognitive interventions.

The last part of the literature review is dedicated on working memory in patients with mild cognitive impairment (MCI). Mild cognitive impairment is a construct which refers to an intermediate and transitional state between normal cognitive changes due to aging and early symptoms of dementia, such as Alzheimer's disease (Petersen, 2006, 2008, 2011). Dementia is becoming more and more important as a public health issue and it is crucial to develop tools that can identify people in early stage of this condition in order to be able to offer them the appropriate level of support, care, and evidence based interventions. In the section on working memory in patients with mild cognitive impairment it has been described the diagnostic criteria, subtypes, the diagnostic scheme, neuropsychiatric symptoms, prognosis and therapy as well with the neuropsychology of this diagnostic category. In the last paragraph of this section a specific focus has been given on working memory impairments, since it has been observed that it declines in these kind of patients (Brant et al. 2009; Cheng at al., 2008; Espinosa et al., 2009; Gagnon and Belleville, 2011; Klekociuk et al., 2014; Nordlund et al., 2005; Saunders, Summers, 2011, 2012; Belleville et al., 2011; Lopez, 2005) progressively from healthy aging to degenerative disease (Belleville et al., 2007; Gagnon & Belleville, 2011). Working memory can have a relevant role in the screening assessment for patients with mild cognitive impairment because some studies observed a reduced maintenance in binding information (Brant et al., 2009; Kessel et al., 2010, Logie et al., 2015; Germano et al. 2008). Moreover, it has also been demonstrated impairment to the central executive of working memory and difficulties to use appropriate strategies and rule acquisition (Summers & Saunders, 2011) causing a direct consequences in every day functioning (Aretouli & Brandt, 2010) for these patients. Considering the data from the literature, the main goal of the third study on visuo-spatial bootstrapping (chapter four) was to examine the performance of typical elderly people compared with a sample of people with mild cognitive impairment. A further objective of this investigation was to offer a contribution to the understanding of the mechanisms involved in the transition from a normal to a pathological ageing which is a sensitive phase where interventions could be made. No visuo-spatial bootstrapping effect was expected to be found considering the data emerging from the literature as described above. However, a bootstrapping effect could be speculated to be found taking in mind the recent finding by Race et al. (2015) who described the presence of the effect in a group of amnesic patients.

Experiment three might provide beneficial findings in a context where there are no efficient treatment for patients with MCI (Ritchie & Tokko, 2010; Callaway, 2012).

Pharmacological treatment for patients with mild cognitive impairment and dementia seem to have only moderate effects on behaviour, cognition and function (Winblad et al., 2004). On the contrary cognitive interventions might have favourable effects in these types of patients (Belleville et al., 2006; Kinsella et al., 2009; Simon, Yokomizo, & Bottino, 2012; Unverzagt et al., 2007). For these reason, visuo-spatial bootstrapping could offer a contribution being a potential tool of cognitive interventions.

The following chapters are the tree experimental studies based on the literature review on: working memory and executive functions, binding processes and working memory in older adults and in patients with mild cognitive impairments.

Experimental chapters

CHAPTER 2

STUDY 1

Visuo-spatial bootstrapping (VSB) and the contribution of subcomponents of working memory: Central Executive suppression

2.1 Introduction

Study one aims to use the visuo-spatial bootstrapping (VSB) paradigm to examine the contribution of subcomponents of working memory to the combination of verbal and spatial information in visual-spatial bootstrapping, based on stored long-term knowledge. The goal is to verify how the central executive system contributes to combine information implicitly.

Study one is based on research which found that information from different modalities, such as verbal and visuo- spatial, is first analysed in their specific modalities and later processed by the episodic buffer (Baddeley et al., 2011). This perspective is supported by studies on verbal and visuo-spatial binding which discovered that articulatory suppression could impact negatively on working memory verbal-spatial binding (Morey, 2009). Allen and colleagues (2015) observed that articulatory suppression had a negative impact on digit recall performance both in single and typical keypad conditions, with a larger effect for digit recall in the single location condition. This observation proves that a familiar distributed pattern of information both facilitates verbal recall performance and reduces the reliance on phonological working memory. This data strongly suggests that bootstrapping involves integration of long-term memory with visuo-spatial short-term trace (Allen et al., 2014) demonstrating that digit recall is better when digits are presented within a familiar spatial keypad array instead of in a single location array. This recent study also replicates the visuo-spatial bootstrapping effect observed by Darling and colleagues in previous studies (2012, 2014; Darling & Havelka, 2010).

Study one relies on the dual-task paradigm, which is a procedure used in experimental psychology that has previously been widely used in driving theoretical developments (Baddeley, 2007). Studies utilising this logic required participants to perform two tasks at the same time. The idea is to understand if the two tasks interfere with each other and compete for a single resource. The multi component model received support using this technique (Baddeley & Hitch, 1974; Hitch & Baddeley, 1976; Baddeley, 1997).

This procedure was applied in this study, in which visually presented digit sequences, both in single or in a typical keypad display, were administered under conditions of verbal working and central executive memory load.

Articulatory suppression (AS)

Articulatory suppression (AS) is a technique which asks participants to repeatedly articulate a simple word or phrase in order to disrupt verbal recoding of visually presented stimuli, while at the same time attempting to prevent articulatory rehearsal strategies (Baddeley et al., 1975; Baddeley, Lewis, & Vallar, 1984; Murray, 1968). Articulatory suppression has been often used for the purposes set out in the current study (Baddeley et al., 1975, 1984; Larsen & Baddeley, 2003; Morey & Cowan, 2004, Morey, 2009). Articulatory suppression prevents verbal coding strategies to be used in support of visuo-spatial working memory (Brown et al., 2006; Mate et al., 2012) and allows exploring visual and verbal working memory. This technique was adopted in order to explore the effect on digit recall of concurrent verbal activity.

This methodology was adopted in a previous study on visuo-spatial bootstrapping (Allen et al., 2015). Articulatory suppression was used again for this present study as comparison task with the executive control load.

Executive Control (EC) load

In this study executive control load was implemented to examine how memory for digits presented within a familiar spatial configuration such as a telephone keypad, and in a single location can rely on executive functions.

The task used for the executive suppression during visual bootstrapping test was selected from a study conducted by Baddeley, Emslie, Kolodny and Duncan (1998). They set up two different tasks, one of those concerning the recitation of two well-known sequences of numbers and letters. Participants were asked to perform either as single sequences, or numbers or words separately (1, 2, 3, 4, etc; A, B, C, D, E, F, etc.) or mixed together, alternating both sequences (1, A, 2, B, 3, C, 4, D, etc.). The other one involved two other familiar sequences, namely days of the week and months of the year. For example recited independently such as Monday, Tuesday, etc., or January, February, March, etc., or alternated, such as Monday, January, Tuesday, etc.

For study one, avoiding using numbers was necessary (given the numeric nature of the visual bootstrapping test), we opted instead for the two familiar sequences of days of the week and months of the year. Other studies have used backward counting to assess the costs of attentional load, such as the experiments conducted by Brown and Brockmole (2010).

Given that both conditions (single digit and typical keypad) involve attention to stimuli presented visually and to the highly cognitive demanding concurrent task, a substantial effect of central executive load on performance, with no bootstrapping effect, was expected to be found. The hypothesis lies on the consideration that the bootstrapping effect involves the operation of many modality-specific and modality-independent systems. As a consequence, it can be assumed that visuo-spatial bootstrapping will be selectively impaired by concurrent tasks. This means that it would expect to discover a greater impact of central executive suppression both on the typical keypad condition and on the single digit display, because central executive is involved in processing to-be-remembered verbal sequences in general (Baddeley et al. 2009; St Clair-Thompson & Allen 2013). On the other hand, considering that it has been demonstrated that visuo-spatial bootstrapping is implicit and links to other forms of binding that are also automatic, it can alternatively be predicted that we would observe a visuo-spatial bootstrapping effect under central executive load. In support of this speculation there are several studies which observed that many forms of binding may develop automatically, without requiring attention (e.g. Allen et al., 2006, 2009; Baddeley et al., 2010; Baddeley et al., 2009; Berlingeri et al., 2008; Karlsen et al., 2009; Rossi-Arnaud, Pieroni, & Baddeley, 2006). This alternative hypothesis is in accordance with Prabhakaran and colleagues (2000) and Langerock and colleagues (2014) conclusions about the role of attention in cross-domain binding. They found that the role of attention is not crucial during the maintenance of feature bindings in visual working memory. Their findings support the idea that in order to maintain verbal-spatial information there is no need of more attentional resources than for verbal or spatial features.

Given the bootstrapping effect involves combining information from verbal and spatial domains, the aim of this present study was to investigate how central executive could contribute to cross-domain binding, and the potential implications on models of working memory. It was predicted to replicate previous studies of a visuo-spatial bootstrapping effect under articulatory suppression comparing the two display conditions (Allen et al., 2015). A negative effect of central executive suppression was also predicted on performance in each of the display conditions.

2.2 Method

The main measure of interest in this study is based on the test of bootstrapping (Darling & Havelka, 2010; Darling et al., 2012). A 2x2 repeated measures design was implemented, manipulating display type (single vs. typical keypad) and concurrent task (executive load vs. articulatory suppression). The visual-spatial bootstrapping task compared performance across two conditions: single location (SD – where all digits are presented in a single location) and typical keypad (TKP – where digits are presented by highlighting them on a numeric keypad that is familiar to participants as being the typical mobile phone keypad). The difference between the two display conditions lay in the way that the to-be-remembered digits were presented.

There were 20 trials at each list length in the Single Digit (SD) and Typical Keypad (TKP) condition. No suggestion as to what memory strategy to use was given. Each participant was tested at their own span minus two (SPAN -2), assessed in a pre-test before taking part in the visual bootstrapping test. Participants were asked to remember random sequences of digits using Single Digit displays for the pre-test.

All subjects took part in all four conditions within a single session. The whole procedure took no longer than 1 hour and it was administered in a quiet room at Queen Margaret University. All participants were asked to provide informed consent (Appendix 1) for research participation. The consent procedure ensures that participants are aware that they can stop at any time. Moreover, an Information Sheet was given to every participant before the experiment session and the Debriefing Statement after it (Appendix 1). In the

Information sheet it was specified that if they agree to participate in the study, they were asked to remember a sequence of digits for few seconds as a computerised test to assess working memory. After the administration of the test they received the explanation about the study and the debriefing information sheet.

All data were anonymised as much as possible. When data were recorded participant number was used instead of their names. All responses to this study were recorded to asses accuracy later. All recordings were stored confidentially.

This project received approval from the Research Ethics Committee at Queen Margaret University.

2.3 Participants

This study included 51 participants (11 males, 40 females; median age: 26,2 years, SD = 6,4, range 19 to 41; median years education: 16,4, SD = 1.7, range 13 to 18). All were students or staff members at Queen Margaret University and native English speakers. Participants were recruited through an online advertisement on Moderator system of Queen Margaret University. Students participated for course credit.

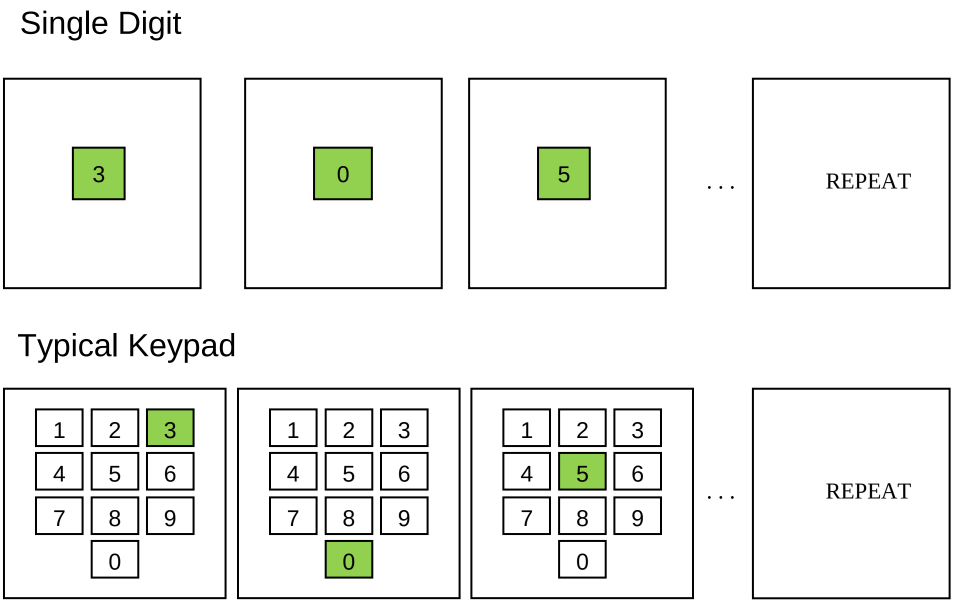
A priori analysis of sample size was carried out using G*Power 3 (Faul, Erdfelder, Lang & Buchner, 2007). To achieve a statistical power of > .8 for direct comparisons within group with a large effect size requires a sample of 36 participants in total. Our sample met and exceeded these criteria.

2.4 EXPERIMENTAL TEST- Bootstrapping task

2.4.1 Materials

Figure 12 shows the displays used in the two display conditions, each for two times. A laptop PC with a 15 inch display was used to present the stimuli, which were compiled using e-prime 2 (Psychology Software Tools, 2013).

Figure 12. Symbolic representation of the different presentation conditions, each showing how the digits 3, 0 and 5 would be presented. Digits were presented for 1500ms, with an inter digit interval of 250ms, followed by a 1000ms retention interval prior to recall when the instruction Repeat appears on the screen.



2.4.2 Pre- test

Each session started with the span test as a pre-test, in order to determine sequence length to use for each subject. In this pre-test participants were asked to carry out a trial at a given sequence length, beginning with just one item, implemented with length progressively increased from two to ten digits. If they remembered one trial, they would then progress to the next sequence length. Whereas if they failed to remember the first sequence, subsequently another trial of the same length was administered. Testing procedure was ended if they failed to recall both sequences in order. Span was then determined to be the maximum sequence length at which participants recalled at least one sequence correctly.

2.4.3 Procedure

The items were randomly sequenced between the digits zero to nine with no digit repeating itself in any list. The participant started the session by pressing a key on the keyboard. Then, a fixation cross was displayed in the centre of the screen with no time limits, followed by a display in which the sequence of to-be-remembered numbers were shown. Digits were always presented in Arial font, 36 point size and were presented centrally within squares with a green background and side of 120 px. The participants performed verbal serial recall with as much time as they wished to complete this. Once all digits in the given trial had been shown, the participants were asked to repeat the digits aloud in the correct order. Having completed the trial, participants continued with the next trial by pressing a key.

Participants were tested across the four display conditions at their maximum span for the single digit condition minus two (SPAN -2). The decision to use span-2 came out after piloting with four subjects who decided to voluntarily take part to the study. Performing the bootstrapping test and concurrent task with the maximum span sequence length was very difficult to accomplish.

2.4.4 Experimental trial

After the pre-test, participants received an information sheet (Appendix 1) with the instructions about the procedure in order to clarify with some examples the tasks to be performed. The four experimental conditions contained 20 test trials each. They performed at the original span minus two sequence span length (SPAN -2).

Each participant received four different conditions in a counterbalanced order: Single Digit - articulatory suppression; Typical Keypad - articulatory suppression; Single Digit - central executive suppression; Typical Keypad - central executive suppression.

Articulatory suppression and central executive suppression were performed from the point of fixation through to the end of the sequence presentation.

In the **articulatory suppression** conditions participants were required to repeatedly vocalise days of the week or the months of the year starting from a random day or month at a rate of approximately one per second. At the same time participants had to remember as many numbers on the display (single and typical keypad) as they could while saying the sequence verbally. Each trial started pressing a key on the keyboard by the subject. As soon after the fixation point, a sentence like this appeared in the middle of the screen for 3000ms "Please say the days of the week or the months of the year beginning with Wednesday. Begin now…". Participants had to start saying: Wednesday, Thursday, Friday, Saturday, Sunday, Monday, etc. After that, they had to continue saying the days of the week or months of the year until the sequence of numbers stops.

During this process, the numbers appeared on the screen and they had to memorise them. When the numbers disappeared, they had to stop saying the days of the week or the months of the year and say the sequence of numbers aloud. In this way the researcher could write them down.

In the **central executive suppression** conditions participants were required to repeatedly vocalise days of the week mixed with the months of the year starting from a random day or month. At the same time participants had to remember as many numbers on the display (single and typical keypad) as they could while saying the sequence verbally as in the other condition. For example, after the fixation point, in the middle of the screen, they read a sentence such as "Please say the days of the week and the months of the year beginning with "Wednesday- April". Begin now…" visible for 3000 ms. Participants had to start saying "Wednesday- April, Thursday- May, Friday- June, Saturday- July, Sunday- August, Monday- September, etc." As in the articulatory suppression condition, subjects were asked to memorise numbers which appeared on the screen and then say the sequence of numbers aloud.

Single digit (SD) display

A fixation cross appeared in the centre of the screen, followed by a display in which the to-be-remembered numbers were shown. For each trial a different sequence of the day of the week or/mixed months of the year was asked to be said. Therefore, a different message was set up for each trial for 3000ms before the sequence of digits, followed by 500ms fixation point.

Digits were presented in a single square (with a green background) in the middle of the screen of a laptop for 1500ms with a 250ms interval between digits, during which the screen was blank. Digits were presented in the Arial font, 36 point size. After the final digit, there was a retention interval of 1000ms, following which the message “Repeat” appeared in the middle of the screen and participants attempted to verbally recall the sequence of digits in the correct order, without a time limit. No suggestion as to what memory strategy to use was provided.

Typical keypad (TKP) display

In the TKP condition, the digits zero to nine were presented in the same array used in a traditional telephone keypad, aligned centrally on the screen in 20 trials (see Figure 14). The digit sequences were shown by highlighting individual digit backgrounds in green. There was a horizontal and vertical spacing of 10px between the outlines surrounding each digit. The sequence of digits was indicated by successively highlighting the background of the digits in the to-be-remembered sequence, in green, for 1500ms, at which point the background fill reverted to clear. Between items, the entire array was cleared for 250ms.

For the typical keypad conditions, the same procedure described in the single digits display was used.

2.5 Methods of scoring

Two different methods of scoring have been used to investigate the visuo-spatial bootstrapping effect in the past. The aim of both of them was to detect the level of accuracy of the sequences of digits to be remembered. In each trial participants tried to remember a random sequence of digits in their correct order.

The total correct trials (TCT) method of scoring was to verify if the sequence of digits was correct or not. The final score for each condition was the total numbers of trials in which all items had been correctly recollected. This was the method adopted in all previously published studies on bootstrapping, apart from Allen and colleagues (2015) in which the proportion correct (PCI) was used.

In the proportion of correct items (PCI) method of scoring the proportion of items on any given trial recalled in the correct serial position was calculated. So if sequence was 1 2 3 4 5, scoring were as follows in the Table 1.

Table 1. Table showing the two different methods of scoring: total correct trials (TCT) and proportion of correct items (PCI).

TOTAL CORRECT TRIALS (TCT)	PROPORTION OF CORRECT ITEMS (PCI)
1 2 3 4 5 : 1	1 2 3 4 5 : 1
1 2 3 4 : 0	1 2 3 4 : 0.8
1 2 4 3 : 0	1 2 4 3 : 0.6
1 2 4 : 0	1 2 4 : 0.4
1 3 5 : 0	1 3 5 : 0.2
2 3 4 5 : 0	2 3 4 5 : 0

In the total correct trials method, only the first string of numbers were considered correct and all the others incorrect. In a different way, in the proportion of individual correct items procedure, only the last sequence of digits was considered completely incorrect because all items one to four are in an incorrect serial position, and nothing was recalled in serial position five.

2.6 Results

Due to errors in counterbalancing three participants were excluded from all reporting. The remaining 48 participants achieved a mean span score of 6.47 (SD = .73; min = 6, max = 8) and for span -2 = 4, 43 (SD = .70; min = 4, max =6) in the pre-test.

Our main focus of attention was the effect of central executive load and articulatory suppression across the display conditions both single digit and typical keypad.

As can be seen in Figure 11, more items were remembered in the TKP condition than in the SD. This pattern was apparent both for executive load and articulatory suppression conditions.

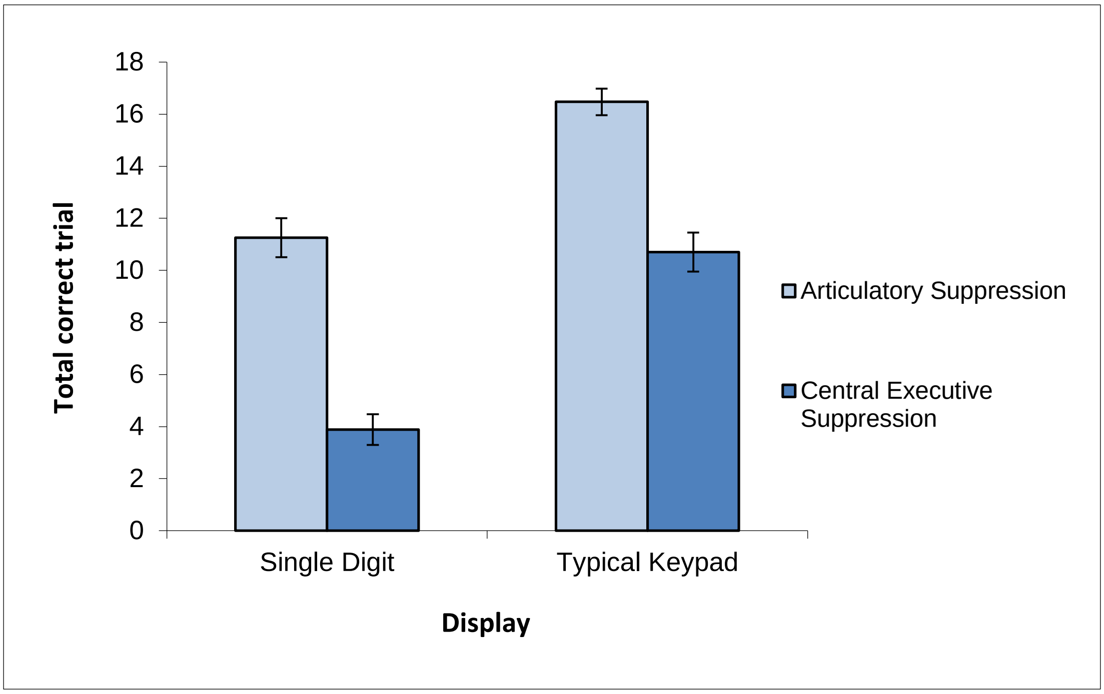
2.6.1 Total correct trials (TCT)

Using the total correct trial (TCT) method of scoring a 2 (display type) x 2 (load) repeated measures ANOVA for related groups revealed significant effects of display type, F (1, 47) = 132.27, η_p^2 = .73, p < .001, and central executive load, F (1,47) = 170.97, η_p^2 = .78, p < .001, indicating superior recall for digits in the keypad condition relative to single digit displays, and a substantial negative effect of central executive suppression. In addition, there was not a significant interaction between display type and concurrent task, F (1, 47) = 3.14, η_p^2 = .06, p =.083.

Further analyses revealed a significant effect of central executive suppression for single display t (47) = 10.96, p < .001 (d = 1.60) (one-tailed) and for typical display t (47) = 8.71, p < .001 (d = 1.25) (one-tailed). There was a significant effect of display in the articulatory suppression condition t (47) = -7.27, p < .001 (d = 1.06) (one-tailed) and executive load condition t (47) = -10.79, p < .001 (d = 1.60) (one-tailed).

There was bootstrapping effect in both articulatory suppression and executive load conditions. The main focus of attention was comparison of performance across the display conditions and how central executive and phonological loop contribute to cross-domain binding. More items were remembered in the typical keypad display than in the single digit display in both conditions (AS and CE).

Figure 13. Graph showing total correct trials (scores ranging from zero to twenty) across display types (Single Digit, Typical Keypad) and conditions (articulatory suppression and central executive load). Error bars represent standard error of the mean.



2.6.2 Proportion of correct items (PCI)

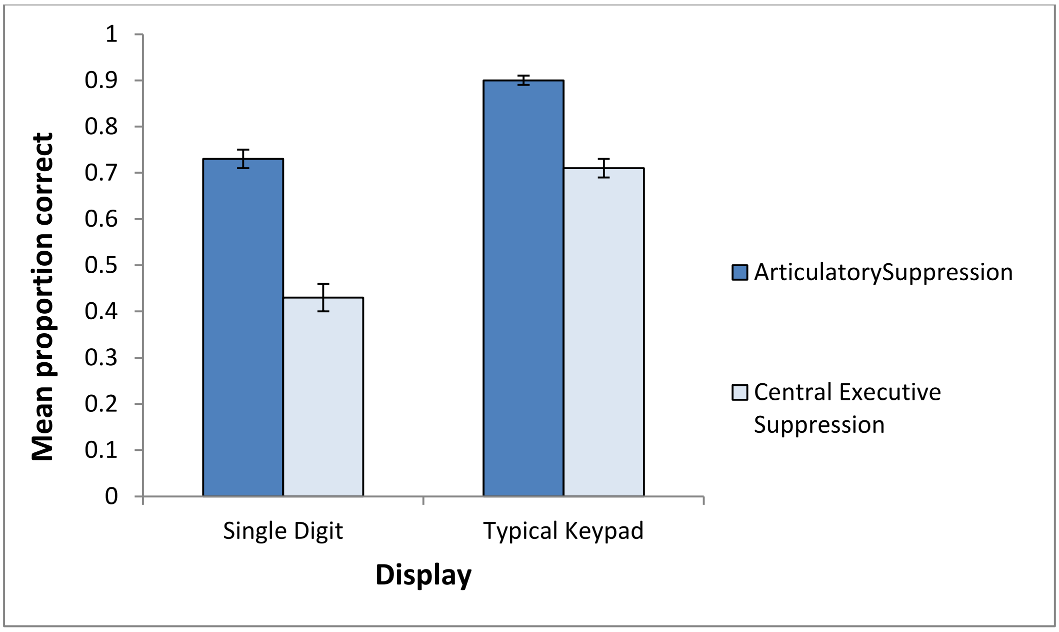
Using the proportion of correct items method (PCI), the proportion of items on any given trial recalled correctly in the correct serial position was calculated. Similar results to the total correct trial method were found.

As can be seen in Figure 12, more items were remembered in the Typical Keypad -TKP condition than in the Single Digit- SD. This pattern was apparent both for executive load and articulatory suppression conditions.

A 2 (display type) x 2 (load) repeated measures ANOVA revealed significant effects of display type, F (1, 47) = 122.92, η_p^2= .72, p < .001, and central executive load, F (1, 47) = 123.44, η_p^2= .72, p < .001. This indicates superior recall for digits in the keypad condition relative to single digit displays, and a substantial negative effect of suppression. In addition, there was a significant interaction between display type and concurrent task, *F* (1, 47) = 12.13, η_p^2= .205, *p* < .001.

Further analyses revealed a significant effect of central executive suppression for single display *t* (47) = 10.68, *p* < .001 (*d* = 1.6) (one-tailed) and for typical display *t* (47) = 7.59, *p* < .001 (*d* = 1.10) (one-tailed). Moreover, it has been noted a significant effect of display in the articulatory suppression condition *t* (47) = -7.17, *p* < .001 (*d* = -1.06) (one-tailed) and executive load condition t (47) = -10.69, *p* < .001 (*d* = -1.60) (one-tailed).

Figure 14. Graph showing mean proportion correct across display types (Single Digit, Typical Keypad) and conditions (articulatory suppression and central executive load) using the proportion of individual correct items method. Error bars represent standard error of the mean.



Bayes factors analyses were conducted. They offer a way to state evidence for one proposition in comparison to another (Edwards, Lindman, & Savage, 1963).

To assess the weight of evidence in favour of interaction effects a full model containing all main effects and interactions and remove a component at a time was constructed. The resulting Bayes factor (B_(R, F)) expresses the evidence for the reduced model over the full model. A BF greater than 1 implies evidence against the interaction, whereas < 1 denotes evidence for the interaction (note that: B_ (F, R) = 1/(B_(R,F)). Bayes factors were calculated using the ANOVA BF function from the Bayes Factor package in R (Morey & Rouder, 2015; R Core Team, 2015) with the "which Models" argument set to top. Each Bayes Factor was sampled until the proportional error was below 5%.

Analysis of total correct trials (TCT) gives a BF of 1.49 against the task by presentation interaction. For the proportion correct items (PCI), however, the weight of evidence is in favour of the interaction (B_(R, F) = 4.78). In summary, there is evidence against the interaction for TCT and stronger evidence for the interaction in PCI.

2.7 Discussion

This study replicated the advantage in digit recall for the typical keypad displays over the single display condition indicating the visuo-spatial bootstrapping effect (Allen et al., 2015; Darling & Havelka, 2010; Darling et al., 2012, 2014) to be a consistent and reliable effect.

Central executive load had a substantial negative effect on digit recall performance in both typical keypad and single display condition, revealing an expected role of central executive in digit recall (Baddeley & Hitch, 1974). These results also demonstrate the bootstrapping effect does not need to recruit phonological loop and executive resources or processes. These findings clearly demonstrate the marginal role of verbal and executive systems in combining information implicitly.

This data show that meaningful spatial information such as a telephone keypad facilitates verbal recall performance and reduces reliance during verbal memory tests on a phonological system and central executive working memory. Bootstrapping can carry on even if phonological loop and central executive are loaded by a secondary task. These findings replicated the main effect that was observed in the previous study for the articulatory suppression (Allen et al., 2015) and extend it with central executive load condition. Digit recall was superior following the keypad presentation and executive load negatively impacted on performance. These results have been obtained with both methods of scoring, total correct trials and mean proportion correct items. The findings using the proportional correct score suggests that visuo-spatial bootstrapping might not only be automatic, but this might protect from performance decrements caused by reduced attentional availability. Moreover, these findings were also confirmed using the Bayesian ANOVA for both the analysis of total correct item method of score (TCT) and proportions correct item (PCI). It has been noted a weak evidence for the interaction for TCT, and stronger evidence for the interaction in PCI.

Taking into account the results of the previous studies (Allen et al., 2014; Darling et al., 2010, 2012, 2014) with these current results, it can be said that this pattern of findings provides new insights for models of working memory. These observations analyse the role of attention and sub-systems which might contribute to the interaction with stored knowledge in long-term memory. It seems that visuo-spatial bootstrapping does not need the central executive resources. The visuo-spatial bootstrapping effect seems to support the role of the episodic buffer within the model of working memory by Baddeley (2000, 2007). This effect can be served by the episodic buffer which was described as a component that connects modality-specific components (visuo-spatial and verbal), central executive and long-term memory. In addition, this model of working memory is supported by research based on visuo-spatial bootstrapping effect which responds to different forms of concurrent disruption (articulatory suppression and executive load) in a clear and predictable way. This indicates a dynamic relationship between cross-domain storage and specialised processing capacities demonstrating the flexible nature of working memory involving various processes that manage several different situations (Morey, 2009). Another consideration to take into account linked with the results of this current study is how the original conception of episodic buffer has been changed in recent years. While initially it was conceived reliant on executive control (Baddeley, 2000), recently it has been demonstrated that it can work automatically, being independent from attentional load (Baddeley et al., 2011). Returning to working memory theory, the episodic buffer has proven to be a useful and productive addition to the working memory model (Baddeley, 2000). At present, however, there is no adequate and straightforward tool with which to assess it. It is possible that visuo-spatial bootstrapping may be helpful in meeting this challenge.

It has also been noticed, through extensive practice using a ‘mental abacus’ strategy, subjects with a normal span for letters can perform a better digit span task. This shows that trained knowledge of visuo-spatial materials can employ long-term memory to reinforce digit memory (Hatano & Osawa, 1983). On the contrary, the power of visuo-spatial bootstrapping has been demonstrated in experiments with children and young adults which have indicated that this effect does not require extended practice or specific cognitive skills to manifest itself (Darling et al., 2014).

Articulatory suppression and executive load used in this study display better the role of the episodic buffer bringing out the complex relation of sub components of working memory. The episodic buffer is a system which passively store multidimensional information from different systems with distinctive codes (Baddeley et al., 2010).

Executive load was investigated for the first time with visuo-spatial bootstrapping task. The role of domain-general attention in maintenance was already investigated in previous studies demonstrating that memory for verbal, visual and spatial material relies on the attentional load of concurrent processing (Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007; Vergauwe, Barrouillet, & Camos, 2009, 2010). More recently, however, Langerock and colleagues (2014), in their study of memory for visually presented verbal information, spatial locations, of verbal-spatial binding, suggested that attention does not play an exceptional role in the maintenance of feature bindings in visual working memory.

In the current study, central executive load demonstrated have a considerable negative effect on digit recall performance in both display conditions. The data demonstrated the lack of central executive involvement in visuo-spatial bootstrapping; even though overall performance decreased in the central executive load condition, the advantage of spatially distributed presentation is maintained. It can be noted that the performance may even be improved under such circumstances, such as in the interaction on the proportion correct items (and a trend toward it in the number correct overall).

It could be also interesting to investigate how central executive load could impact the performance on visuo-spatial bootstrapping in groups of older people and patients with dementia, who display a significant decrease in this function (Baddeley, 2002).

Moreover, it can be interesting to investigate the visuo-spatial bootstrapping considering the observations by Miyake and colleagues (2000) about the nature of the executive functions (see chapter one). They suggested (Miyake, et al., 2000) a fractional nature of the executive functions. The executive function of shifting, updating and inhibition are separable constructs, but at the same time correlated and not entirely independent of each other. Further studies may take into account the controversy unity versus diversity of the executive functions with three studies investigating the three different types of executive functions with respect to visuo-spatial bootstrapping.

2.8 Conclusions

In sum, the present study demonstrates that the visuo-spatial bootstrapping advantage is a reliable construct responding in contrasting logical ways to dual task manipulations. The accessibility of familiar verbal-spatial patterns facilitates digit recall. At the same time, the processes of visuo-spatial bootstrapping does not add executive demand and maintenance in verbal working memory.

CHAPTER 3

Study 2

Visuo-spatial bootstrapping (VSB) in older and younger adults

3.1 Introduction

The current study was designed to investigate whether visuo-spatial bootstrapping (VSB) effect is observed in an older adult sample compared to younger. Study two consisted of a comparison of visual-spatial bootstrapping in older and younger samples of non-neurologically impaired individuals.

In order to achieve this objective two selected groups of young and older adults were recruited to compare their performances on visuo-spatial bootstrapping tasks. The effect in older adults was compared against a sample of younger adults, so that any lifespan related changes could be identified. As in previous studies (Darling et al. 2010, 2012, 2014), a single digit condition was contrasted with a typical keypad condition and a random keypad condition. A random keypad was included because it can be used to estimate the degree to which a familiar representation of a particular spatial (presumably in long-term memory) array is necessary for the observation of facilitation due to bootstrapping in older adults.

Given that older adults show difficulties to retain the associations between different features (Naveh-Benjamin & Kilb, 2014) and the performance in binding of verbal and spatial information is not efficient as in younger adults (Meier et al., 2014), no bootstrapping effect might be expected to be found. However, in contrast, considering that visuo-spatial bootstrapping seems to be fairly automatic and data obtained in the previous study (chapter two) demonstrated the marginal role of central executive in combing information implicitly a bootstrapping effect could be hypothesised to be identified.

3.2 Method

A sample of older and younger adults was recruited. Each participant was assessed with a brief neuropsychological battery of tests and the bootstrapping test material (described below). This battery measured the cognitive functions with Mini Mental Status examination (MMSE; Folstein, Folstein, & McHugh, 1975), intellectual capacity with Raven's Coloured Progressive Matrices (RCPM; Raven, 1993), verbal memory span with Digit Span forward & backward test (Wechsler, 1997), visual memory function with the Visual Patterns Test (VPT; Della Sala et al., 1997) and span of spatial memory with Corsi Block Tapping test (Spinnler & Tognoni, 1987). These tasks were implemented to ensure that participants were ageing in a typical (rather than atypical) pattern. The main measure of interest in this study is based on the test of bootstrapping (Darling & Havelka, 2010; Darling et al., 2012). The latter task compared performance across three conditions: single location (SD – where all digits are presented in a single location), typical keypad (TKP – where digits are presented by highlighting them on a numeric keypad that is familiar to participants as being the typical mobile phone keypad) and random keypad (RKP – same as the TKP condition, but using an unfamiliar keypad arrangement) without suggestion as to what memory strategy to use. Display type was included as a within-subjects factor and age group as a between-subjects factor to implement a 2 (age group) x 3 (display condition) design. The relevant difference between these three display conditions lies in the way that the to-be-remembered digits are presented. Moreover, participants were given a brief interview to exclude those with serious health problems or those on medication that can cause drowsiness or affect cognitive functioning. All participants were asked to provide informed consent (Appendix 2) for research participation. Moreover, every participant was given the Information Sheet before the experiment session and the Debriefing Statement afterward (Appendix 2). The participants were offered the chance to understand the aim of the research, with the possibility to clarify any of doubts. While also providing them with my contact information, along with the contact of an independent advisor from Queen Margaret University.

All data was anonymised. When data was recorded the participant number was used instead of their names. All responses to this study were recorded to assess accuracy later. All recordings was stored confidentially.

This project received approval from the Research Ethics Committee at Queen Margaret University.

3.3 Participants

Participants who entered the study were composed of two groups. The first group was composed of young adults (19-35 years old), who had been recruited from students of the University of Bari and wider Bari community (Italy). The other sample was composed by older adults (55-76 years old), who have been recruited from the cultural association for older people called “Orizzonti” in Bari (Italy).

A total of 110 participants entered into the study. Samples of 55 older adults (mean age: 63, SD = 6, range: 55 to 76; years of formal education: 12.23, SD = 4; 34 females) and 55 younger adults (mean age: 28, SD = 3.98, range: 19 to 35; years of formal education: 15.9, SD = 2.53; 30 females) were recruited. *A priori* analysis of sample size was carried out using G*Power 3 (Faul, Erdfelder, Lang & Buchner, 2007). To achieve a statistical power of > .8 for repeated measures comparisons with a medium effect size requires a sample of 83 participants in total (43 per group). Our sample met and exceeded these criteria.

3.4 Materials

All the participants have completed the following battery of neuropsychological tests before performing the computerised bootstrapping tests (Appendix 2).

3.4.1 Background tests

List of background test used to screen younger and older subjects.

3.4.1. 1 Mini Mental Status Examination (MMSE)

The Mini Mental Status Examination (Folstein et al., 1975) is a widely used screening test in clinical practice for the assessment of cognitive function and to estimate the severity of cognitive impairments (Tierney et al., 2003) specifically with the elderly population. Moreover, it has received an international acceptance for researching cognition and dementia (Chatfield et al., 2007; Grober et al., 2008) and has been suggested by the National Institute for Health and Clinical Excellence (NICE) as the primary marker of severity of Alzheimer's disease (Burns et al., 2010).

It consists of thirty points grouped into seven cognitive areas, including test of orientation to place and time, registration, attention and concentration, recall, language and visuo-spatial skills. It is easy to administer and takes approximately five to ten minutes. The total score ranges from zero to thirty (representing the number of completed items) and cut off score of 23/24 provides a good sensitivity for the detection of cognitive impairments and early phases of dementia (Folstein et al., 2000).

It has been confirmed by extensive psychometric data that the MMSE has very good test-retest and joint reliability. Also processing excellent validity, and is sensitive to cognitive decline in patients with Alzheimer's disease with scores decline an average of 1.8–3.2 points per year (Folstein, Folstein, & McHugh 2000).

3.4.1.2 Raven's Coloured Progressive Matrices (RCPM)

Raven's Progressive Matrices (Raven, 1993) are multiple choice nonverbal tests of intellectual capacity and abstract reasoning, originally developed by Dr John C. Raven in 1936, widely used in research and clinical settings (Jensen, 1987; Arthur & Day, 1994). In each test item, participants are asked to identify the missing segment required to complete a larger pattern. The individual's task is to complete series of drawings, selecting the appropriate one from a range of possible choices. Many items are presented in the form of a 3x3 or 2x2 matrices, giving the test its name. There are three different versions of matrices for participants with different ability: Standard Progressive Matrices, Coloured Progressive Matrices and Advanced Progressive Matrices.

The Coloured Progressive Matrices (RCPM) were designed for younger children, elderly, and people with learning difficulties. This version test contains sets A and B from the standard matrices, with a further set of 12 items inserted between the two, as set Ab. Most items are presented on a coloured background with only few items in set B are presented as black-on-white.

The test correlates with many indices of intellectual functioning (Marshalek, Lohman, & Snow, 1983). Sex differences do not appear to be significant.

3.4.1.3 Digit Span forward and backward

Tests of forward and backward digit span (Wechsler, 1955, 1981, 1997) are the most widely used neuropsychological tests of short-term verbal memory (Richardson, 2007; St Clair-Thompson & Allen, 2013). These test were used in the Wechsler batteries: the intelligence scales (Wechsler, 1981) and Wechsler Memory Scale WMS and WMS-R (Wechsler, 1997). The Digit Span is made up of two different tests: the Digits Forward (repeating digits forward) and Digits Backward (repeating digits backward) which employ short-term phonological storage (short-term memory).

The backward recall requires also an attention-demanding transformation of the digit sequence, classifying this task as a complex span measure of working memory (Alloway, Gathercole & Pickering, 2006). According to this observation, studies have revealed that backward recall loads onto working memory, whereas forward recall refers to a separable short-term memory factor (Alloway, Gathercole, Willis, & Adams, 2004; Gathercole, Pickering, Ambridge & Wearing, 2004).

The test consists of pairs of numbers. The examiner reads the sequence of numbers and when the sequence is followed by the correct answer, the examiner reads the next sequence, which is longer than the previous. This procedure continues until the subject fails to recall a couple of sequences or repeats the last correct sequence consisting of nine numbers.

3.4.1.4 Corsi Block Tapping test

Corsi block tapping tests (Spinnler & Tognoni, 1987) measures the span of visuo-spatial memory. Specifically the amount of visual-spatial information that can be hold in recent memory or short-term memory (De Renzi & Nichelli, 1975; Spinnler & Tognoni, 1987). The stimulus is made up of a wooden board on which is glued nine cubes arranged asymmetrically. The examiner is sitting in front of the subject, and with the index finger, touches the cubes in a standard sequence of increasing length (from two to ten cubes). Soon after the demonstration of the sequence, the examiner asks the subject to reproduce it by tapping the cubes in the same order. Three sequences are presented for each serie. If the subject correctly reproduces at least two out of three sequences, the procedure goes on the more difficult next series. The number of cubes in the longest series (for which they have successfully reproduced at least two sequences) is the test score which represents the span of spatial memory of a given subject. The average span of memory space is approximately equal to five, but significant differences have been found between mean scores by age and schooling. On the contrary gender was not found to be statistically significant in samples of adults and elderly (Spinnler & Tognoni, 1987). On a sample of university students there were statistically significant differences in performance between males and females. The results favour the former (Orsini, Trojano, Chiacchio, & Grossi, 1982), as indeed is common in tasks which involve processing of spatial relationships.

3.4.1.5 Visual Pattern Test (VPT)

The Visual Patterns Test (VPT; Della Sala et al., 1997) is a measure of visual working memory that has been designed for use both as a clinical and a research context. Commonly used measures of non-verbal short-term memory are loaded with a spatial component. The measures of non verbal short-term memory most widely used in neuropsychology is the Corsi Blocks Test (Corsi, 1972), which requires the subject to tap specified blocks in sequence, reproducing a series of different spatial locations.

In the VPT a series of black and white checkerboard-like patterns of increasing complexity is required to the subjects to memorise. These matrices are difficult to code verbally and no sequencing is required.

Statistical analysis of data showed robust associations of VPT with years of education and chronological age. VPT has high test-retest and equivalent forms of reliability. Moreover, a low correlation between VPT and Corsi Blocks Test has been found in healthy subjects, in brain-lesioned patients and in clinical populations like patients affected by dementia. This confirms that the two tests are not tapping the same processes. This means that VPT measures visual, as opposed to spatial, non-verbal short-term memory (Della Sala et al., 1997).

3.5 EXPERIMENTAL TEST- Bootstrapping task

3.5.1 Design

Participants were tested at their own span, and assessed during a pre-test. They were asked to remember random sequences of digits using Single Digit (SD) displays. Display type was included as a within-subjects factor and age group as a between-subjects factor to implement a 2 (age group) x 3 (display condition) design. The difference between these three display conditions lay in the way that the to-be-remembered digits were presented in the three conditions, Single Digit (SD), Typical Keypad (TKP) and Random Keypad (RKP). There were 30 trials at each list length.

3.5.2 Materials and Procedure

Figure 13 shows the displays used in the three display conditions. A laptop PC with a 15 inch display was used to present the stimuli, which were compiled using e-prime 2 (Psychology Software Tools, 2013).

3.5.3 Pre test

Participants were tested across the three display conditions at their maximum span for the single digit condition, which was assessed in a pre-test. In this pre-test participants were asked to carry out two trials at a given sequence length, beginning with one item. If they remembered at least one trial, they would then progress to the next sequence length. However, if they failed to recall either sequence the procedure stopped. Span was then determined to be the maximum sequence length at which participants recalled at least one sequence correctly.

3.5.4 Experimental test- Visuo-spatial bootstrapping (VSB)

3.5.4.1 Procedure

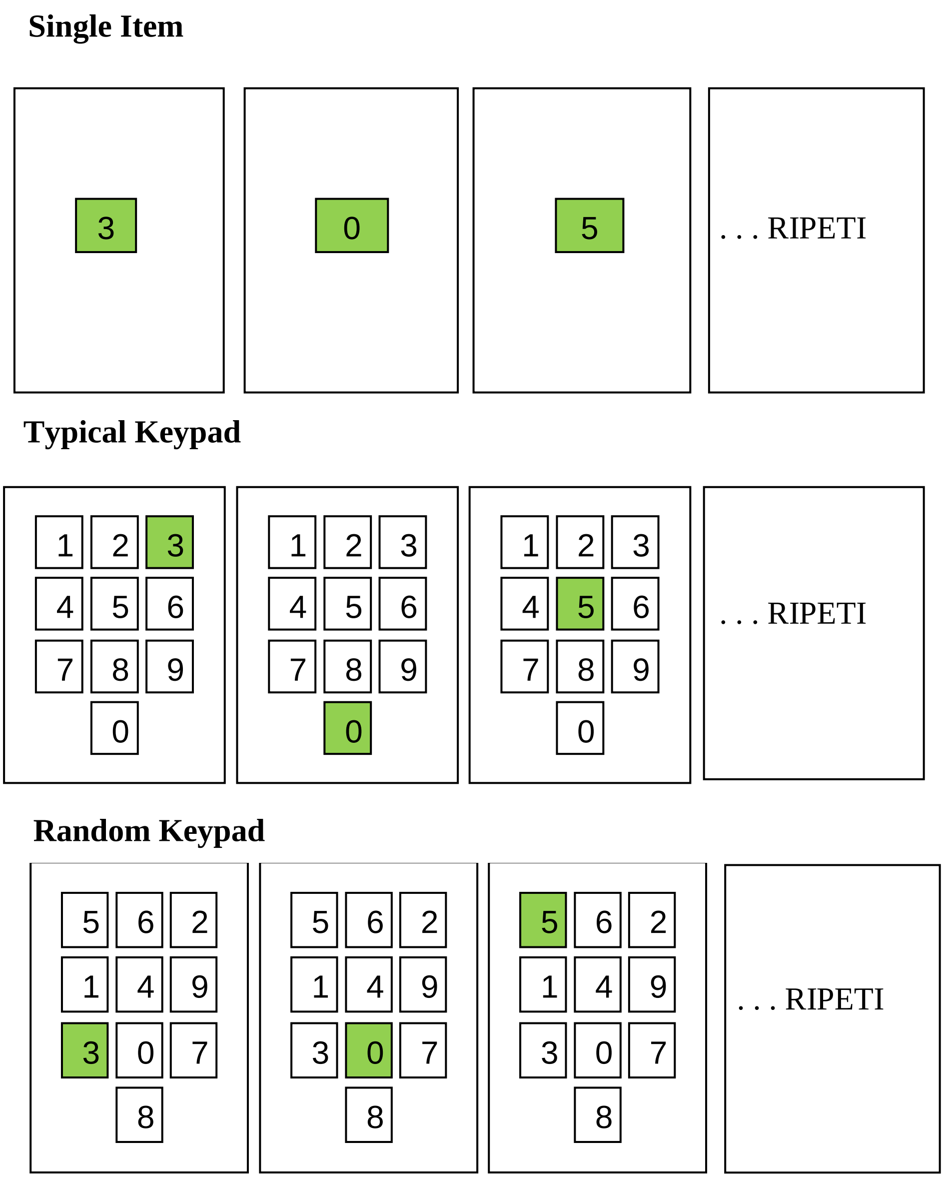
The to-be-remembered items were random sequences of the digits zero to nine with no digit repeated in any list. Participant started the session by pressing a key on the keyboard. No suggestion as to what memory strategy to use was provided. Then, a fixation cross was displayed for 500ms in the centre of the screen. Followed by a display in which the sequence of to-be-remembered numbers was shown. Digits were always presented in Arial font 26point size and were presented centrally within squares with a green background with side of 120px. Once all digits in the given trial had been shown the participants were then asked to repeat the digits aloud in the correct order. The participants performed verbal serial recall with as much time as they needed to complete this. Having completed the trial, participants continued with the next trial by pressing a key (Figure 15).

The Bootstrapping task used in this study is similar to the one used for the first experiment described in chapter two, but several changes were made according to the different needs of the sample and the aim of the study. The decision to apply several changes came out after piloting with ten subjects (5 younger adults and 5 older adults) who decided to voluntarily take part to the study. Because the aim of this study was different and 3 displays with 30 trials each were necessary, the pilot study assured that older adults did not experience fatigue or difficulties performing the visuo-spatial bootstrapping task. Speed and brightness of the stimuli were also checked. Specifically, three conditions (SD, TKP and RKP) instead of two (SD and TKP) were used with 30 trials presented in each conditions instead of 20. Both single digit (SD) display and typical keypad (TKP) display have been already described in detail in study one (chapter two), wherease random keypad (RKP) display was used only in this present study. The random keypad condition was similar to the typical keypad condition (with a random sequence of digits in 30 trials), except that the locations of the digits were randomised and hence unfamiliar to participants – they did not appear in their typical locations. Following the first trial digit locations remained consistent throughout this condition, however. The language was Italian as study two was carried out in Italy instead of UK.

3.6 Methods of scoring

As for the previous experimental study (chapter two) two different methods of scoring have been used: total correct trial (TCT) and the proportion of individual correct items (PCI). The aim of both of them was to detect the level of accuracy of the sequences of digits to be remembered.

Figure 15. Symbolic representation of the different conditions, each showing how the digits 3, 0 and 5 would be presented. Digits were presented for 1000ms, with an inter digit interval of 250ms, followed by a 1000ms retention interval prior to recall.



3.7 Results

Two participants did not complete the full test session due to fatigue, and hence their data is excluded from all reporting. With regard to overall memory capacity in the single item span pre-test, mean span was 4.76 items (SD = 1.16, min = 3, max = 8) for the group of older adults, whilst it was significantly higher for the younger adult participants (M = 5.81 items: SD = 0.87, min = 4, max = 8, t(106) = 5.33, d = 1.02, $p < .001$). The difference between older and younger adults here was broadly comparable with that observed in the Weschler digits forward task (see Table 2). Though it is noteworthy that performance on visually presented digit span pre-test was somewhat worse for both groups than on the verbally presented Weschler digits forward task.

Table 2. Cognitive profiles of the participants entering the study. An independent-samples t- test was conducted to compare the performance scores for younger and older adults.

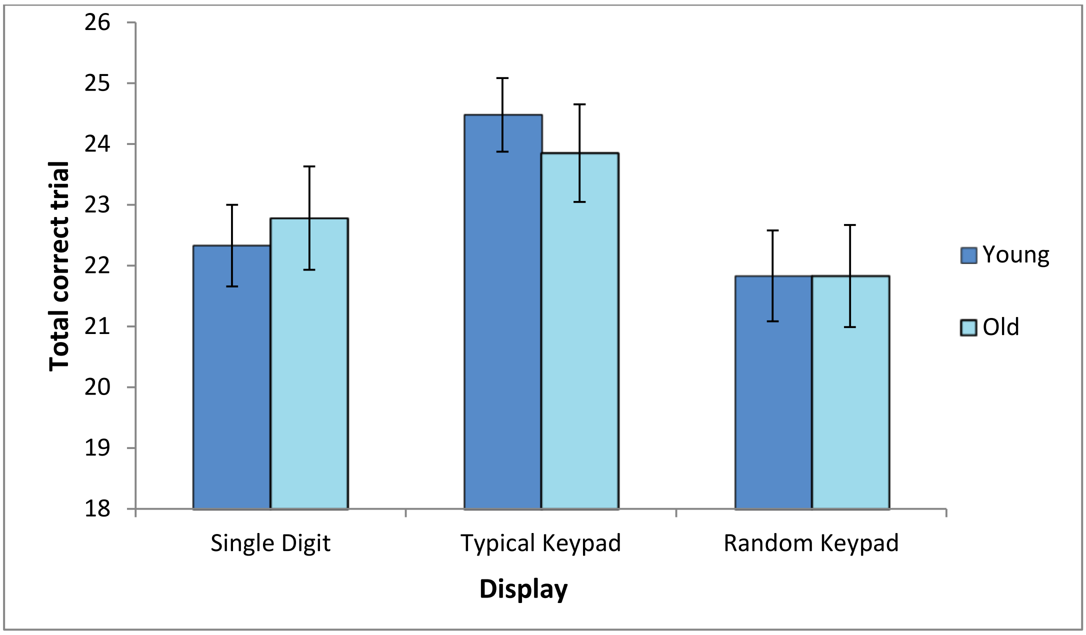
Test	**Younger adults** (N = 54)	**Older adults** (N = 54)	**T**	**P**
Education	15.94 (SD = 2.31)	12.19 (SD = 4.59)	-5.37	.000
Mini Mental State Examination (0-30) cut off: 24 (Folstein et al., 1975)	29.80 (SD = .078)	29.17 (SD = 1.83)	-2.32	.022
Raven's Coloured Progressive Matrices (RCPM) (0-36) (Raven, 1988)	35.24 (SD = 1.42)	31.06 (SD = 4.59)	-6.30	.000
Digit Span forward (2-9) cut-off:3.5 (Wechsler, 1997)	6.24 (SD = .067)	5.56 (SD = 1.02)	-4.11	.000
Digit span backward (2-9) cut off:4.0 (Wechsler, 1997)	4.98 (SD = 1.17)	4.43 (SD = 1.0)	-2.64	.009
Visual Patterns Test (VPT) (1-15) (Della Sala et al., 1997)	9.25 (SD = 1.74)	6.93 (SD = 1.85)	-6.71	.000
Corsi Block Tapping Test (1-9) (Spinnler & Tognoni, 1987)	5.61 (SD = .97)	5.09 (SD = .99)	-2.72	.007

3.7.1 Total correct trials (TCT)

Our main focus of attention was the comparison of performance across the display conditions. As can be seen in Figure 16, more items were remembered in the typical keypad condition than in either the single digit or random keypad conditions. This pattern was apparent both for older and for younger participants. A mixed 2 (age group) x 3 (display type) ANOVA on TCT demonstrated a main effect of display across the two groups (F (2,212) = 16.48, η_p^2= .135, p <.001). Neither the interaction between display type and age group (F (2,212) = .841, η_p^2= .008, p = .433) or the main effect of age group (F (1,106) = .004, η_p^2= .000, p = .949) approached statistical significance. Pairwise comparisons demonstrated that performance in the keypad condition was significantly better than in the single digit condition, (*dz* = 0.39, p < .001) and in the random keypad condition (*dz* = 0.54, p < .001). Performance in the random keypad condition was slightly worse than in the SD condition but not significantly so (*dz* = 0.16, p =.09).

In order to assess the conservative hypothesis that visuo-spatial bootstrapping could be observed independently in each of the age samples, an assessment of the simple main effect of display was carried out in each group independently. This effect was significant in younger adults (F (2,105) = 12.29, η_p^2= 1.90, p < .001) and in older adults (F (2,105) = 5.98, η_p^2= .102, p = .003). Furthermore, performance in the keypad condition was significantly higher in the typical keypad condition than in the single digit condition in both the younger and older samples (younger: *dz* = 0.533 p (one-tailed) < .001; older: *dz* = .254 p (one-tailed) =.03). Performance in the typical keypad condition was significantly better than in the random keypad condition in older adults (dz = 0.49 p (one-tailed) < .001), and in younger adults (dz = .58, p (one-tailed) < .001).

Figure 16. Graph showing accuracy (scores ranging from zero to thirty) across age groups (young and old) and display type (Single Digit, Typical Keypad and Random Keypad) using the total correct trial method. Error bars represent standard error of the mean.



3.5.2 Proportion of correct items (PCI)

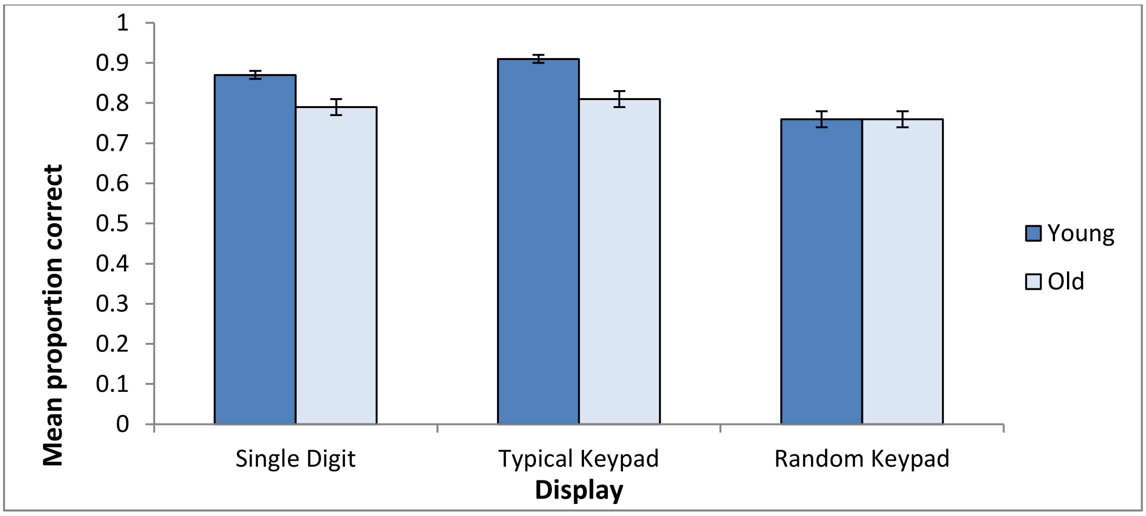
Using the proportion of individual correct items method of scoring (PCI), calculating the proportion of items on any given trial recalled correctly in the correct serial position, similar results were found. As can be seen in Figure 16, more items were remembered in the typical keypad condition than in either the single digit or random keypad condition conditions.

This pattern was apparent both for older and for younger participants. A mixed 2 (age group) x 3 (display type) ANOVA demonstrated a main effect of display across the two groups (F (2,212) = 7.92, η_p^2 = .070, p < .001). The interaction between display type and age group (F (2,212) = 1.02, η_p^2= .010, p = .362) was not statistical significant, whereas the main effect of age group (F (1,106) = 11.20, η_p^2 = .096, p = .001) approached was statistical significance.

In order to assess the conservative hypothesis that visuo-spatial bootstrapping could be observed *independently* in each of the age samples, an assessment of the simple main effect of display was carried out in each group independently. This effect was significant in older adults (F (2,105) = 6.38, η_p^2 = .108, p = .002) but not significant in younger adults (F (2,105) = 2.69, η_p^2 = .49, p = .072).

Pairwise comparisons demonstrated that performance in the typical keypad condition was significant in the random keypad condition in younger adults (dz = 0.48, p < .001) and in older adults (dz = 0.28, p = .035). Furthermore, performance in the single digit condition was not significantly higher than in the typical keypad condition in both younger and older samples (younger: dz = 0.167, p = .176; older: dz = 0.296, p = .057).

Figure 17. Graph showing mean proportion correct across age groups (older and younger) and display type (Single Digit, Typical Keypad, Random Keypad) using the proportion of individual correct items method. Error bars represent standard error of the mean.



As in study one, an analysis using bayes factors was conducted on the interaction. In the total correct score there was good evidence against the interaction, as the reduced model was over 8 times more likely than the full model (B_(R,F) = 8.617). This was also the case in the analysis of proportion correct (B_(R,F) = 7.067). There is strong evidence against the interaction for TCT and PCI.

3.8 Discussion

To our knowledge the present study is the first to investigate visuo-spatial bootstrapping in a sample of older adults, and the principal conclusion is that older adults displayed a comparable visuo-spatial bootstrapping effect to younger adults. Older and younger adults did not differ in terms of the size of the benefit obtained by presenting digits in a familiar keypad array. Additionally, when simple main effects of display were assessed independently for each age group, there was a significant benefit for typical keypads in both groups. Hence we can conclude that visuo-spatial bootstrapping in visually presented immediate serial recall of digits is a phenomenon which persists across the course of typical ageing.

No significant age differences were observed in the bootstrapping pattern, thus there is no evidence of a difference in the beneficial impact of additional visual information between older and younger participants, as evidenced by the lack evidence for an age group x display interaction, once overall differences in digit span were controlled for by testing participants at their individual spans.

Turning attention to the type of displays which produced a visuo-spatial bootstrapping benefit, in both age groups performance in the keypad condition was significantly better than in the single digit and in the random keypad conditions. Hence it is clear that the visuo-spatial bootstrapping effect required the availability of a familiar representation in long-term memory, an observation which is entirely consistent with previous results in younger adults and older children (Darling et al., 2012, 2014). These results were also confirmed using the Bayesian ANOVA for both the analysis of total correct item method of score (TCT) and proportions correct item (PCI).

Taking into account the evidence from previous studies (Darling et al., 2012, 2014), it can now be argued that visuo-spatial bootstrapping seems to develop around nine years of age. Specifically, children six years of age did not show visuo-spatial bootstrapping effect, while nine year old children perform as adult subjects. The bootstrapping effect is absent in six year-olds, but fully present in children of nine years of age demonstrating that it does not proceed along the same trajectory level of maturation as verbal and visuo-spatial working memory; visuo-spatial bootstrapping then tends to remain stable across the lifespan. This pattern is in contrast with other changes that occur with the progression of age. For example, there is clear evidence of declines in several cognitive functions and particularly in complex working memory functions (Jost et al., 2011; Myerson et al., 2003; Chen et al., 2003). Visuo-spatial bootstrapping appears to be relatively robust to cognitive decline, though it is important to note that these are observed in a paradigm whereby initial difficulty is set on a per-individual basis. Therefore the underlying visuo-spatial and verbal memory systems may not be so robust (indeed, the significant difference in performance on the pre-test would suggest that this was the case, at least for verbal short-term memory). Nonetheless, given that the benefit to performance by visuo-spatial bootstrapping seems robust against ageing, it is a potentially fruitful candidate for further research as understanding visual-spatial bootstrapping may assist interventions to assist individuals with age-related memory difficulties.

Fluid cognition (e.g. logical problem solving; Horn & Cattell, 1967) declines over the course of normal ageing (Schaie, 2005). This decline seems to be more so linked with visuo-spatial working memory (VSWM) rather than crystallised intelligence (such as accumulated knowledge, experience and skill) which appears to be linked with verbal working memory (Bergman & Almkvist, 2013). These observations highlight differences in the rates of decline of these two domains of working memory (Dang et al., 2012), with verbal working memory more robust than visuo-spatial working memory. Within this context it is possible that visual-spatial bootstrapping reflects a contribution from visuo-spatial long-term knowledge that can sustain the function of an otherwise declining visuo-spatial working memory. Note, however, that some tasks requiring binding information of different types are impacted by age: for example, Bo and colleagues (2012) demonstrated age-related decline in a task where information about object identity and localisation had to be linked together (Bo et al., 2012). Hence, the robustness of visuo-spatial bootstrapping may be specifically linked to incidental cross-modal binding rather than intentional within-domain binding mechanisms.

Current theories which explain the cognitive difficulties faced by older adults (Cabeza, 2001, 2002; Manan et al., 2013; Kemps & Newson, 2006; Bopp & Verhaeghen, 2005; Park et al., 2002) might seem to predict that visual-spatial bootstrapping would decline over age too, but the present data are not consistent with this. It is possible that visual-spatial bootstrapping can exploit a compensatory mechanism through a plastic reorganisation of neurocognitive networks as described by Cabeza and colleagues (2002) in their HAROLD model (Hemispheric Asymmetry Reduction in Older age) and in the STAC framework (Scaffolding Theory of Aging and Cognition) by Park and Reuter-Lorenz (2009). Specifically, the STAC framework considers the involvement of compensatory cognitive scaffolding and adaptive neural response that is used in the face of cognitive challenge throughout the life span, rather than a process specific to old age. Moreover, taking into consideration findings from the previous study (chapter two) which demonstrate that the bootstrapping effect does not need to recruit executive resources, it is possible to speculate another potential explanation for the results obtained in this current study. Despite the data emerging from the literature on the difficulties to retain the associations between different features (Naveh-Benjamin & Kilb, 2014) and a worse performance in binding verbal and spatial information for older adults in comparison with younger adults (Meier et al., 2014), it has been observed a bootstrapping effect in both groups. The marginal role of verbal and executive systems in combining information implicitly in meaningful spatial information such as a telephone keypad could explain why visou-spatial bootstrapping seems to be robust to cognitive decline.

A potential application of these findings could be a potential cognitive training for older people. Cognitive training in healthy elderly subjects has been well explored teaching both theoretical strategies and skills to improve cognitive functions. It has been observed that these types of training can improve cognitive functions in elderly individuals (Ball, Berch, Helmers, Jobe, Leveck, Marsiske, et al., 2002; Stigsdotter & Backman, 1992) and their effect is visible in a follow-up period of five years (Willis, Tennstedt, Marsiske, Ball, Elias, Koepke, Morris, et al., 2006). An additional positive factor of cognitive training in healthy elderly subjects is that it seems to reduce the risk of cognitive impairments in this population (see meta-analysis by Valenzuela & Sachdev, 2009).

3.9 Conclusion

The aim of this study was to investigate visuo-spatial bootstrapping across the lifespan, with a specific focus on older adults considering that working memory decreases in older people. It emerged that older adults showed an analogous visuo-spatial bootstrapping effect to younger adults with no difference in terms of magnitude of the benefit obtained by presenting digits in a typical keypad array. The main conclusion of this study is that visuo-spatial bootstrapping is an effect which persists across the course of typical ageing.

As in any study of ageing, it is unclear to what extent patterns observed in this study can inform our understanding of degenerative cognitive decline. Future research might try and focus on the investigation of the mechanisms involved in the transition from a normal to a pathological ageing. Moreover, the use of spatially distributed displays to facilitate learning and memory of complex information has a range of potentially useful applications especially in an ageing society with the incidence of neurodegenerative diseases on the rise (Hort, O'Brien, Gainotti, Pirttila, Popescu, Rektorova, Sorbi, & Scheltens, 2011). Examining the cognitive processes underlying the visuo-spatial bootstrapping task could enable the development of clinical tools for assessing long-term memory, visuo-spatial and verbal integration in working memory.
Taking into account findings emerging from studies one (chapter two) and two, further studies may be conducted with older people using the dual task methodology in order to investigate the contribution of subcomponents of working memory with the visuo-spatial bootstrapping task.

The research reported in this chapter has recently been published as a paper with the collaboration of Stephen Darling, Richard Allen and Jelena Hevelka (Calia, C., Darling, S., Allen, R.J., Havelka, J. (2015). Visuospatial bootstrapping: aging and the facilitation of verbal memory by spatial displays. *Archives of Scientific Psychology,* 3, 74–81).

CHAPTER 4

Study 3

Visuo-spatial bootstrapping (VSB) in older adults and patients with Mild Cognitive Impairment (MCI)

4.1 Introduction

Study three is designed to examine performance on the visuo-spatial bootstrapping (VSB) task in a typical elderly sample compared with a sample of people with Mild Cognitive Impairment (MCI) (Petersen, 2004). This current study might help to understand both cognitive and functional problems faced by mild cognitive impairment patients and benefit the identification of the working memory process which are impaired in MCI patients.

As the previous chapter described, mild cognitive impairment is a transitional stage between normal ageing and dementia which involves the onset and evolution of cognitive impairments beyond those expected based on the age and education of the individual; but are not significant enough to interfere with daily activities (Petersen et al., 1999, 2001) (see chapter one). The percentage of older adults with a diagnosis of MCI varies between 3 to 19 in a general population (Gauthier, Reisberg, Zaudig, Petersen, Ritchie, Broich, Belleville, et al., 2006), with a range from 5% to 10% of conversion to dementia (Mitchell & Shiri-Freshki, 2009). Considering the prevalence, it appears crucial to develop better screening tools and at the same time non-pharmacological interventions since there are not effective pharmacological treatments for patients with MCI (Aisen, 2008). In recent years, a growing interest has been observed in cognitive interventions for MCI patients as proper therapeutic approaches (Simon et al., 2012). This new emerging approach originates from the observation of cognitive plasticity in MCI patients, which allows for these subjects to learn new information despite their cognitive difficulties (Calero & Navarro, 2004).

This current study can be a starting point to develop better techniques to help subjects with mild cognitive impairment to remain independent for a longer period of time; patients could benefit from a specific training over and above pure theoretical interest. Mild cognitive impairment is an intermediate stage between normal cognitive changes due to ageing and later symptoms of dementia (Petersen, 2008). With visuo-spatial bootstrapping administration tasks it might be possible to observe if this effect is still present in people with memory difficulties.

The main focus of this study is to understand the bootstrapping effect and its potential impact in an ageing context related to changes from normal ageing to mild cognitive impairment. A number of studies have shown that mild cognitive impairment is associated with a stable pattern of specific deficits to working memory (Gagnon & Belleville, 2011; Saunders & Summers, 2010, 2011, 2012; Brant et al. 2009; Espinosa et al., 2009; Nordlund et al., 2005) with a reduced maintenance of bound information (Kessel et al., 2010, Germano et al. 2008). Furthermore, those patients exhibit difficulties to spatial working memory, visual spatial span and complex sustained attention (Klekociuk & Summers, 2014), show impairments to the central executive (Summers & Saunders, 2011) and in conjunctive and relational binding. Understanding the role of working memory in mild cognitive impairment could be important because it was found to be associated with functional impairments (Aretouli & Brandt, 2010) and might contribute to poor performance on visual paired associate learning (Harel et al., 2011).

In the current study, a Single Digit (SD) and a Typical Keypad (TKP) condition were administered to typical elderly people and a matched control sample of elderly patients with mild cognitive impairment. In order to compare their performances on visuo-spatial bootstrapping tasks. For this study several changes to the bootstrapping task have been made, taking into account the differences due to age and cognitive difficulties in comparison with the other studies. In the study three, both of the groups were composed of older people: typically ageing individuals and subjects with a pathological form of ageing as mild cognitive impairment. The bootstrapping task was changed in order to obtain the best possible performance from both groups and to avoid distress using difficult tasks. This time two conditions (Single Digit and Typical Keypad) instead of three (Single Digit, Typical Keypad and Random Keypad) were tested with 15 trials presented in each condition rather than 30. In addition, presentation of the stimuli was slower and the digits were larger. This decision arose from the observations of performance by older adults in visual-spatial bootstrapping tasks in study two. Three display types with 30 trials in each condition required a long time of administration that could cause fatigue in MCI subjects.

This study aimed to evaluate whether participants with mild cognitive impairment showed the visuo-spatial bootstrapping effect and if they differed from normal elderly people. Considering that MCI patients show a stable pattern of working memory deficits (Brant et al. 2009; Cheng at al., 2008; Espinosa et al., 2009; Gagnon & Belleville, 2011; Klekociuk et al., 2014; Nordlund et al., 2005; Saunders & Summers, 2011, 2012; Belleville et al., 2011; Lopez, 2005), no bootstrapping effect was expected to be found. On the other hand, considering the recent investigations conducted by Race et al. (2015) which identified that the capacity to integrate verbal information with stored visuo-spatial knowledge is preserved in amnesic patients and the data obtained from previous studies (chapter two and three), it could be hypothesised to find a bootstrapping effect in MCI. In addition, this speculation can also be supported by the observation of central executive deficits in patients who develop dementia later (Baddeley et al., 1991; 1986; Brant et al., 2009; Summers & Saunders, 2011) and the observation in every study of the lack of role of the central executive in visuo-spatial bootstrapping effect.
An additional aim of this investigation is to offer a contribution of understanding the mechanisms involved in the transition from normal to pathological ageing. This is a sensitive phase where interventions could be made.

4.2 Method

The method used was similar to that used in Study two (see chapter three). Each participant was assessed with a brief neuropsychological battery of tests and the test of bootstrapping. The assessment was administered in only one session for older people, while it was divided into two sessions for subjects with mild cognitive impairment in order to avoid fatigue. An extensive neuropsychological assessment was available for the patients with mild cognitive impairment collected as part of a standard clinical procedure to evaluate their cognitive profiles (Mondini, Mapelli, Vestri, Arcara, & Bisiacchi, 2011). Neuropsychological testing is required to demonstrate that patients are below some cut-off points on standardised cognitive tests. The clinician has to determine whether a particular score represents a significant change from a patient's presumed baseline. In order to ascertain this, several testing sessions are usually needed to establish whether the patient's cognitive functions are improving, staying stable, or progressing to full-blown clinical dementia (Landau et al., 2010). In addition, it has to be considered that mood disorders, medical illness, and medications may affect cognition in such a way that a patient will meet criteria for mild cognitive impairment.

Before the clinical assessment, a typical common interview was made with a family member of patients and with others members of the healthcare team (the neurologist in particular) in order to receive further information about the patients and any progression of their difficulties. During these interviews, unstructured queries and structured cognitive assessment tools for patients and informants were used (Crook et al., 1986). This is one of the first steps of clinical standard procedure of diagnosis of MCI.

The first step was the collection of data and information relating to the recent life of the patients regarding their medical history, psychological and cognitive patient's status. Relevant information in this phase could be gathered by speaking directly with the patients or with a family member, and consulting any reports of clinical trials. Most of the time, patients are not completely aware about their daily difficulties and the information and perspective of an informant who lives close to them could be essential to take over a clear picture of their status. It is fundamental to record the results of other clinical examinations, along with the medication that the patients take on a daily basis, as it is very likely that may interfere with cognitive functions.

All the participants of this study received the same cognitive tests as in the previous study (study two), plus other specific tests used only with MCI patients in order to define their cognitive profile. The background battery of tests measured cognitive functions with the Mini Mental Status examination (MMSE; Folstein et al., 1975); verbal memory span with the Digit Span forward and backward test (Wechsler, 1997); visual memory function with the Visual Patterns test (VPT; Della Sala et al., 1997); and span of visuo-spatial memory with the Corsi Block Tapping test (Spinnler & Tognoni, 1987). Visuo-spatial bootstrapping (VSB) test material was also used in this study with some changes according to the needs of the participants. The visual-spatial bootstrapping task compared performance across two conditions: single location (SD) and typical keypad (TKP).

Display type was included as a within-subjects factor and age group as a between-subjects factor to implement a 2 (age group) x 2 (display condition) design. The relevant difference between these two display conditions lied in the way that the to-be-remembered digits are presented.

All participants were asked to provide informed consent (Appendix 3) for research participation. It is relevant to specify that patients with mild cognitive impairment are able to give informed consent because their cognitive functions usually are not impaired, but they show some cognitive difficulties. Moreover, they were aware that may withdraw at any stage of the procedure without fear of any impact on their treatment and without having to give a reason. The consent procedure ensured that participants were aware that they can stop at any time.

An information sheet was given to every participant before the experimental session and the debriefing statement afterward (Appendix 3).

The consent process ensured participants to make an informed choice to participate including an explanation of how confidentiality would be ensured and what data was retained, and in what format. Patients were accompanied by their principal caregiver during testing. Although the caregiver did not have a formal role in the consent process, the testing was not carried out if the caregiver was not in agreement with the participant over their participation.

This project received approval from the Research Ethics Committee at Queen Margaret University.

4.3 Participants

This study included 20 people with mild cognitive impairment (MCI) (14 females, 6 males; median age: 69.2 years, SD = 6.49, range 60-82; median years education: 9,29, SD = 5.11, range 0-18) and 26 matched healthy controls (20 females, 6 males; median age 67.38 years, SD = 6.8, range 60-77; median years education: 10.5, SD = 3.97, range 5- 18). MCI patients were recruited from the Department of Neuroscience of the Hospital and University of Bari, while elderly people were recruited from the cultural association "Orizzonti" in Bari (Italy). Initial MCI diagnosis was made by neurologists, and participants who met the inclusion criteria were invited to participate in the study. Accordingly, a control sample matched on age, gender and years in education was recruited. The two groups did not differ significantly on years of education ($t(41) = -.79$, $p < .431$) and age ($t(41) = .68$, $p = .496$).

Participants were given an extensive interview in order to exclude those with serious health problems and those on medication that could cause drowsiness or affect cognitive functioning.

All the MCI patients had been diagnosed according to formal criteria (Petersen, 2004; Winblad et al., 2004) requiring: 1) change in cognition recognised by the affected individual or by observers; 2) objective impairment in one or more cognitive domains; 3) no presence of dementia. Consistent with these criteria all patients with mild cognitive impairment included in the study had an objective impairment in one or more cognitive functions and had normal activities of daily living (ADL - Katz et al., 1963), as well as instrumental activities of daily life (IADL - Lawton and Brody, 1969). In addition, all the MCI patients had a normal neurological examination by the neurologists of the Hospital of Bari (Italy) (Table 3). The performance of the two groups across a range of neuropsychological tests is reported and compared in Table 4.

Table 3. Inclusion criteria of the two samples of the study: mild cognitive impairment and matched controls of older adults.

MCI	- Diagnosis was made by neurologists according to formal criteria (Petersen, 2004; Winblad et al., 2004) requiring: 1) change in cognition recognised by the affected individual or by observers; 2) objective impairment in one or more cognitive domains; 3) no presence of dementia. 4) normal performance in activities of daily living No medication that could cause drowsiness or affect cognitive functioning - Italian native
OLDER	Control sample matched on age, gender and years in education - No known cognitive impairments - No serious health problems - No medication that could cause drowsiness or affect cognitive functioning - Italian native

4.4 Materials

4.4.1 Background tests

The following tests were administered including the Mini Mental Status examination (MMSE; Folstein et al., 1975); Raven's Coloured Progressive Matrices (RCPM; Raven, 1988); Digit Span forward and backward test (Wechsler, 1997); Visual Patterns Test (VPT; Della Sala et al., 1997); and Corsi Block Tapping test (Spinnler & Tognoni, 1987). All these tests were described in detail in the previous experimental chapter (Appendix 2).

4.4.2 Neuropsychological tests for MCI

List of neuropsychological tests used to screen patients with Mild Cognitive Impairment (MCI) in addition to those used for the study (Appendix 3).

4.4.2.1 Frontal Assessment Battery (FAB)

Frontal Assessment Battery (FAB) (Dubois, Slachevsky, Litvan, & Pillon, 2000) is a short battery of cognitive-behavioural survey for screening global executive dysfunctions. It consists of six subtests that explore several tasks which are conceptualisation (category), mental flexibility (verbal fluency), programming (standard motor), susceptibility to interference (conflicting instructions), inhibitory control (go-no-go) and the autonomy from the environment (stimulus of understanding). It is quick tools aimed at evaluate executive functions.

For each item a score from zero (wrong answer) to three (correct) can be assigned, on a total of 18 points.

4.4.2.2 Prose Memory Test: immediate recall and delayed recall

Prose Memory Test: immediate recall and delayed recall (Spinnler & Tognoni, 1987) is a test assessing long-term verbal memory. The examiner asks the subject to recall the contents of a brief story. In the immediate recall procedure of prose passage, the story is read aloud to the patient with free recall after the presentation and then after ten minutes. The number of information recalled in both conditions are recorded and then scored separatly (Grant & Adamas, 2009). The prose memory test was evaluated using a score that enhances the extraction procedure of the main meanings of the text (Capitani, Della Sala, Laiacona, Maschetti & Spinnler, 1994). The maximum score for each recall is equal to eight and the total is 16 points that must be scored according to the age and level of education (Vallar & Papagno, 2011).

4.4.2.3 Constructive apraxia

Copying drawings of geometric figures (Arrigoni & De Renzi, 1964; Spinnler & Tognoni, 1987; Wechsler, 1945, 1987) is one of the tests of the manual apraxia battery. Twelve constructional apraxia test stimuli with different levels of complexity were given to participants with a pencil and piece of paper. Subjects were asked to copy geometric figures. The administration of this test is individual. Every figure was scored using a rating scale from zero (no impairment) to four (severe impairment) (Taira, 1991).

4.4.2.4 Visual search

Visual search (Spinnler & Tognoni, 1987) is a visual selective attention test composed by three different matrices to complete in 45 seconds. Each matrix is composed by 13 lines of ten numbers from zero to nine each, arranged in a random sequence. The subject should block all numbers the same as those printed on top of the matrix ("5" in the first, "2-6" in the second, "1-4-9" in third). The maximum time for each array is 45 sec, but it still allows the subject to finish the task in case they need a longer time. If the subjects takes less than 45 seconds to complete the individual matrix, the experimenter must indicate the time used. The score is calculated with the number of correct answers (range zero to sixty overall in the three matrices).

4.4.2.5 Trail-Making Test (TMT)

Trail-Making test (TMT) (Spreen & Strauss, 1998; Giovagnoli, Del Pesce, Mascheroni, Simoncelli, Laiacona, & Capitani, 1996) is a timed paper and pencil test of perceptual motor tracking that requires conceptual flexibility. This test provides information about visual search, scanning, mental flexibility, executive functions and speed of processing. The test is split into two different parts: TMT-A and TMT-B. Task requirements of TMT-A are similar to the TMT-B, with the exception that numbers have to be alternated to letters in the latter. For both tasks, the participant is asked to connect with a line in ascending order all the numbers as accurately and quickly as possible, while the examiner measures the time. Once the test begins, the examiner starts the stopwatch and measures how many seconds it takes the patient to end the test. The score on each part is the amount of time required to complete the task (Lezak, 2004; Spreen & Strauss, 1998).

4.4.2.6 Phonemic Word Fluency

The purpose of the Phonemic Word Fluency test (Spreen & Benton, 1977) is to assess the magnitude of the lexical inventory, the ability to access the lexicon and lexical organisation (Lezak, Howienson, & Loring, 2004). There are various forms of this test. The well-known version uses three phonemes f, a and s, asking to produce words starting from those letters. This test is also known as the Controlled Oral Word Association Test (COWAT), F-A-S test, word fluency etc. (Steiner, Mansur, Brucki, & Nitrin, 2008). The examiner asks the participant to say all the words that come to mind with a certain letter, not admitting personal names or cities. The time available is one minute for each letter. If the participant reports a person's name or city it is necessary to remind them of the instructions, without stopping the stopwatch. A word repeated more than one time should marked with an "R". The final score is the sum of the individual words produced by the patient (Novelli, Papagno, Captains, Laiacona, Vallar & Cappa, 1986).

4.4.2.7 Stroop Test

Stroop Test **(**Caffarra et al., 2002) measures selective attention, cognitive flexibility and processing speed. It is used as a tool to assess the executive functions (Spreen et al., 2006) in disorders such as brain damage, dementias and other neurodegenerative diseases. There are several test variants used in clinical settings but all versions have at least two subtasks. In one trial, the written colour name differs from the colour ink printed in, and the participant has to say aloud the written word instead of color ink. In another trial, the participant has to name the ink colour instead. In this study the former version was used. The score is the time that it takes to complete each of the trials plus the number of errors (Howieson, Lezak, & Loring, 2004).

4.4.2.8 Clock Drawing Test

The Clock Drawing Test (Shulman, Shedletsky, & Silver, 1986) is often used in cases of cognitive impairment and dementia. Originally the test was carried out to evaluate the ability of praxis construction of objects' mental representation. As well as planning and memory and the ability to understand verbal instructions, this is often altered in patients with cognitive impairment. The subject is presented with a blank sheet of paper with instructions to draw a clock, with no time limits. There are two different modalities in the mode of administration of this test. In one modality, subjects are asked to draw the clock from memory. Alternatively, the experimenter draws the quadrant and the subjects only have to add numbers by drawing them into the quadrant. For this study, the first modality of administration was used. There are three areas of evaluation: the accuracy of the numbers, the arrangement of the numbers, the arrangement of the hands and their length (O'Rourke, Tuokko, Hayden & Beattie, 1997).

4.4.2.9 Geriatric Depression Scale (GDS)

Geriatric Depression Scale (GDS; Brink et al., 1982) is a questionnaire used for the assessment of depressive symptoms in the elderly and is often used in patients with cognitive impairment. The test consists of 30 items with binary response (yes / no). The score ranges from zero (no depression) to thirty (severe depression). The severity of depression can be divided into different age groups: zero to ten- absent, 11 to 16- mild to moderate depression and 17 or more- severe depression (Yesavage, Rose, Lum & Huang, 1983).

4.4.2.10 Activities of Daily Living (ADL) and Instrumental Activities of Daily Living (IADL)

Activities of Daily Living (ADL) (Katz, Ford, Moskowitz, Jackson, & Jaffe, 1963) and Instrumental Activities of Daily Living (IADL) (Lawton & Brody, 1969) are two scales that assess activities of daily living. The ADL tasks are related to personal care. They include questions about bathing, dressing, toileting, moving. Each individual item can vary from zero (complete dependence) to six (complete independence).

IADL is a scale that assesses complex skills that guarantee independence. These skills include using the telephone, shopping, preparing food, managing the house, doing the laundry, taking public transportation, taking medications, using money. The scale consists of eight items and the result can range from zero (complete dependence) to eight (complete independence).

This neuropsychological assessment an average takes one to two hours according to the cognitive performance of every single person.

This screening assessment was administered before the experimental tasks in a different session. In this way, time was given to the patients to think about the participation on the research and read the information sheet with the chance to ask questions. Then, an appointment was arranged in a separate day in accordance with patient needs. The experimental task took approximately 30 minutes to be completed. The study was conducted in a quiet room at the Hospital of Bari (Italy), guaranteing to patients a safe and confidential environment.

Healthy ageing participants were recruited and assessed at the headquarters of the same cultural association in Bari as in the previous study. Each participant was assessed with a brief neuropsychological battery of tests (background tests 6.4.1). A formal consent by the president of the association was obtained as part of the Queen Margaret University Ethical approval process.

4.5 EXPERIMENTAL TEST- Bootstrapping task

The Bootstrapping task used in the third study is broadly similar to the one used for the second study described in the chapter three, but several changes were made according to the different needs of the sample. Specifically, two conditions (Typical Keypad and Single Digit) instead of three (Typical Keypad, Single Digit and Random Keypad) were used with 15 trials presented in each condition instead of 30. Presentation of stimuli was slower and the size of digits was larger. The decision to apply several changes came out after piloting with ten subjects (5 older adults and 5 MCI) who decided to voluntarily take part to the study. The pilot study was carried out in order to verify that older adults and MCI patients could perform the experimental test without experiencing fatigue or difficulties.

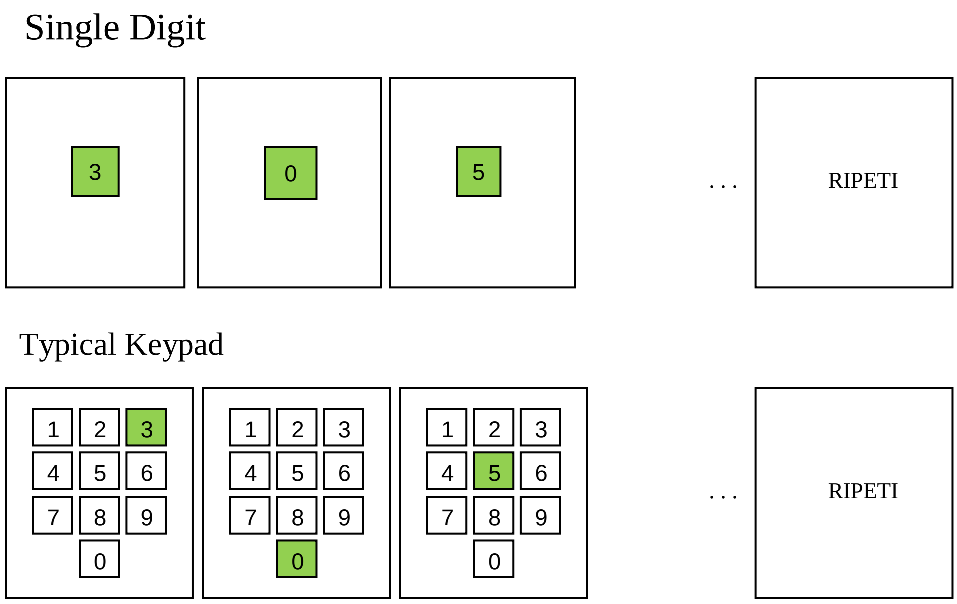
4.5.1 Design

Participants were tested at their own span, assessed in a pre-test. They were asked to remember random sequences of digits using Single Digit (SD) displays. Display type (Typical Keypad and Single Digit) was included as a within-subjects factor and group as a between-subjects factor to implement a 2 (MCI and older adults) x 2 (display condition) design. The difference between these two display conditions lay in the way that the to-be-remembered digits were presented.

4.5.2 Materials and Procedure

Figure 18 shows the displays used in the two display conditions. A laptop PC with a 15 inch display was used to present the stimuli, which were compiled using e-prime 2 (Psychology Software Tools, 2013).

Figure 18. Symbolic representation of the different presentation conditions, each showing how the digits 3, 0 and 5 would be presented. Digits were presented for 1500ms, with an inter digit interval of 250ms, followed by a 1000ms retention interval prior to recall when the instruction "Ripeti" (Repeat) appears on the screen.



4.5.2 Pre- test

Participants were tested across the two display conditions at their maximum span for the single digit condition, which was assessed in a pre-test. In this pre-test participants were asked to carry out a trial at a given sequence length, beginning with just one item. If they remembered one trial, they would then progress to the next sequence length. On the contrary, if they failed to remember the first sequence, another trial of the same length was administered. However, if they failed to recall both sequences the procedure stopped. Span was then determined to be the maximum sequence length at which participants recalled at least one sequence correctly.

4.5.3 Procedure

The to-be-remembered items were random sequences of the digits zero to nine with no digit repeating itself in any list. The participant started the session by pressing a key on the keyboard. Then, a fixation cross was displayed in the centre of the screen with no time limits, followed by a display in which the sequence of to-be-remembered numbers were shown. Digits were always presented in Arial font, 48point size and were presented centrally within squares with a green background and side of 120px. The participants performed verbal serial recall with as much time as they needed to complete it. Once all digits in the given trial had been shown, the participants were then asked to repeat the digits aloud in the correct order as soon after the “Ripeti” (Repeat) cue. Having completed the trial, participants continued with the next trial by pressing a key.

4.5.5 Experimental test

Single digit (SD) display

In each trial participants tried to remember a random sequence of digits in 15 trials (Figure 19). The sequence length was set at the single item capacity measured in the pre-test. Digits were presented in a single square (with a green background) in the middle of the screen of a laptop for 1500ms with a 250-ms interval between digits, during which the screen was blank. Digits were presented in the Arial font, 48point size. After the final digit, there was a retention interval of 1000ms, following which the message "Ripeti" ('Repeat') appeared in the middle of the screen and participants attempted to verbally recall the sequence of digits in the correct order, without a time limit.

Typical keypad (TKP) display

In the TKP condition, the digits zero to nine were presented in the same array used in a traditional telephone keypad, aligned centrally on the screen in 15 trials (see Figure 19). The digit sequences were shown by highlighting individual digit backgrounds in green. There was a horizontal and vertical spacing of 10px between the outlines surrounding each digit. The sequence of digits was indicated by successively highlighting the background of the digits in the to-be-remembered sequence, in green, for 1500ms, at which point the background fill reverted to clear. Between items, the entire array was cleared for 250ms.

4.6 Methods of scoring

As for the previous studies (chapter four and six) two different methods of scoring have been used: total correct trial (TCT) and the proportion of correct items (PCI).

4.7 Results

Tables 8 and 9 detail the background cognitive measurements of participants in this study. With regard to overall memory capacity in the single digit span task pre-test, mean span was 3.90 items (SD = 1.61, SE= .36; min = 2, max = 7) for the group of MCI, while the mean span for older adults was 4.50 items (SD = .81, SE= .15; min = 4, max = 8). The span length was not significantly lower for the MCI participants (t (44) = - 1.64, p = 0.10) with a small effect size (*d* = 0.05).

Table 4. Cognitive profiles of the participants entering the study. An independent-samples t-test was conducted to compare the performance scores for older adults and MCI performing background tests.

Test	**Cut off**	**MCI** (N = 20)	**Older adults** (N = 26)	**T**	**P**
Age		69.1 (SD = 6.19) (SE = 1.38)	67.62 (SD = 6.74) (SE = 1.32)	.76	.44
Education		9.75 (SD = 4.76) (SE = 1.06)	10.58 (SD = 4.18) (SE = .82)	-.62	.53
Mini Mental State Examination (0-30) (Folstein et al., 1975)	> 24	23.70 (SD = 5.56) (SE = 1.24)	27.54 (SD = 3.20) (SE = .62)	-2.94	.00
Digit Span forward (2-9) (Wechsler, 1997)	> 3.5	4.65 (SD = 1.38) (SE = .31)	4.92 (SD = .93) (SE = .18)	-.79	.43
Digit span backward (2-9) (Wechsler, 1997)	> 4.0	2.95 (SD = .99) (SE = .22)	3.54 (SD = .90) (SE = .17)	-2.09	.04
Visual Patterns test Test (VPT) (1-15) (Della Sala et al., 1997)		5.16 (SD = 1.53) (SE = .35)	5.85 (SD = 1.61) (SE = .31)	-1.43	.15
Corsi Block Tapping Test (1-9) (Spinnler & Tognoni, 1987)		4.31 (SD = .80) (SE = .18)	4.58 (SD = .64) (SE = .12)	-1.27	.21
SPAN		3.90 (SD = 1.61) (SE = .36)	4.50 (SD = .31) (SE = .15)	-1.64	.10

Table 5. Cognitive performances achieved by the MCI patients performing an extensive neuropsychological battery of tests in addition to the background tests used for the study (see previous table).

Test	**MCI** (N = 20)
Frontal Assessment Battery (0-18) (Dubois et al., 2000)	13.30 (SD = 2.51) (SE = .60)
Prose Memory - Immediate recall (0-8) (Spinnler & Tognoni, 1987)	3.13 (SD = 2.51) (SE = .61)
Prose Memory - Delayed recall (0-8) (Spinnler & Tognoni, 1987)	2.32 (SD = 2.64) (SE = .60)
Phonemic word fluency (Spreen & Benton, 1977)	25.5 (SD = 9.70) (SE = 2.16)
Stroop –Time (Stroop, 1935)	27.70 (SD = 17.72) (SE = 3.96)
Stroop –Errors (Stroop, 1935)	4.47 (SD = 8.92) (SE = 1.99)
Visual search (0–60) (Spinnler & Tognoni, 1987)	42.50 (SD = 11.40) (SE = 2.55)
Trail-Making Test (TMT) A (Spreen & Strauss, 1998; Giovagnoli et al., 1996).	68.45 (SD = 32.21) (SE = 7.70)
Trail-Making Test (TMT) B (Spreen & Strauss, 1998; Giovagnoli et al., 1996).	90.95 (SD = 85.77) (SE = 19.18)

Clock Drawing Test (0-9.5) (Shulman et al., 1986)	6.80 (SD = 3.41) (SE = .80)
Constructive apraxia (Spinnler & Tognoni, 1987)	16.10 (SD = 12.10) (SE = 2.70)
Geriatric Depression Scale (GDS) (0-30) (Brink et al., 1982)	7.3 (SD = 5.96) (SE = 1.33)
ADL- Activities of Daily Living (0-6) (Katz et al., 1963)	0 (SD = .00) (SE = .00)
IADL- Instrumental Activities of Daily Living (0-8) (Lawton & Brody, 1969)	0.10 (SD = 0.44) (SE = .10)

4.7.1 Total correct trials (TCT)

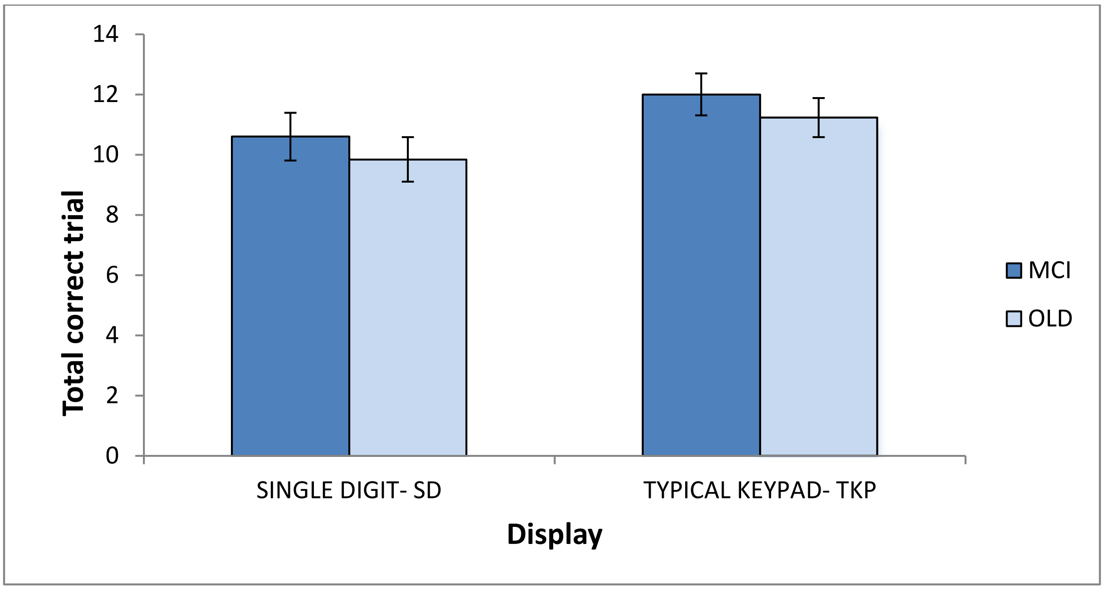
As it can be seen in Figure 20, more items were remembered in the TKP condition than in the SD conditions. This pattern was apparent both for older and MCI participants. A mixed 2 (group) x 2 (display type) ANOVA on TCT demonstrated a main effect of display across the two groups (F (1, 44) = 7.90, partial eta squared = .15, p = .008): however, the main effect of group was not statistically significant (F (1, 44) = 0.72, η_p^2 = .01, p = .401).

The interaction effect between display type and group was not statistically significant (F (1, 44) = 0.00, η_p^2 = .00, p = .98).

The main effect of display type reflected that there were differences in memory performance across the two conditions (single location and standard keypad) and across the two groups. This study indicates a substantial bootstrapping effect in both groups.

In order to assess the conservative hypothesis that bootstrapping could be observed independently in each sample, an assessment of the simple main effect of display was carried out in each group independently. This effect was significant in MCI patients (F (1, 44) = 3.51, η_p^2 = .074, p = .034 (one-tailed)) and in the group of elderly (F (1, 44) = 4.46, η_p^2 = .092, p = .020 (one-tailed)).

Figure 19. Graph showing accuracy (scores ranging from zero to fifteen) across groups (older people and Mild cognitive impairment patients- MCI) and display type (typical keypad and single digit) using the total correct trial method of scoring. Error bars represent standard error of the mean.

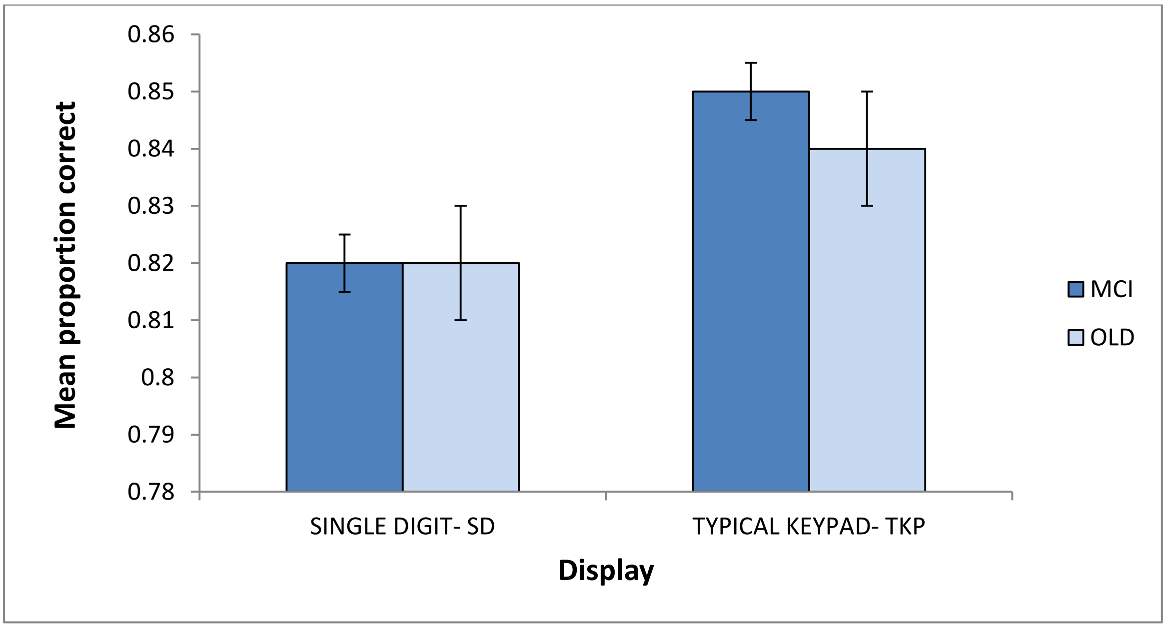


4.7.2 Proportion of correct items (PCI)

Using the proportion of individual correct items method of scoring, calculating the proportion of items on any given trial recalled correctly in the correct serial position, different results were found. As can be seen in Figure 21, more items were remembered in the typical keypad condition than in the SD conditions. A mixed 2 (group) x 2 (display type) ANOVA demonstrated that there is no evidence of a significant main effect of display across the two groups. There was not a substantial main effect of display across the two groups (F (1, 44) = 2.18, η_p^2 = .05, p = .15), and the interaction effect between display type and groups was not statistically significant (F (1, 44) = .15, η_p^2 = .00, p = .71). The main effect of group was not statistically significant (F (1, 44) = .03, η_p^2 = .00, p = .88).

In order to assess the conservative hypothesis that bootstrapping could be observed independently in each sample, an assessment of the simple main effect of display was carried out in each group independently. This effect was not significant in MCI patients (F (1, 44) = 1.52, η_p^2 = .033, p = .224) and in the group of elderly (F (1, 44) = .690, η_p^2 = .015, p = .411).

Figure 20. Graph showing mean proportion correct across age groups (older people and Mild cognitive impairment patients- MCI) and display type (Single Digit- SD, Typical Keypad- TKP) using the proportion of individual correct items method. Error bars represent standard error of the mean.



For the analysis of total correct item method of score (TCT), the Bayesian ANOVA of the data from study 3 revealed over 3-to-1 evidence against the interaction (B_(R, F) =

3.327). For proportions correct item (PCI) the evidence was less convincing but still against the interaction (B_(R, F) = 1.673). This analysis showed less clear results for PCI, but it seems that both methods of scoring describe the same pattern of results using Bayes analysis (ie. a lack of interaction).

4.8 Discussion

The purpose of this study was to understand how patients with mild cognitive impairment perform in bootstrapping tasks in order to clarify the difference with older adults.
The bootstrapping effect was investigated for the first time in a group of mild cognitive impairment patients. Apparently contradictory results emerged from the analysis of the same data sets using the two different scoring methods to investigate the visuo-spatial bootstrapping effect. The purpose of both of them was to detect the level of accuracy of the sequences of digits to be remembered. The final score for each condition was the sum of the correct answers. In the proportion of individual correct items method of scoring, the proportion of items on any given trial recalled in the correct serial position was calculated.
The main conclusion is that the bootstrapping effect was present in both in MCI patients and older adults using the total correct trial method of score. On the contrary, when results are scored with the proportion of individual correct items method of scoring, they did not seem to benefit from familiar spatial information. It can be observed that there is a small trend for both groups.
It seems that with a more categorical (success/failure based) evaluation of scores patients with mild cognitive impairment show the bootstrapping effect, while the alternative method (the proportion of individual correct items) seems to incorporate more noise. Perhaps because it includes a mixture of successful and unsuccessful numbers in trials where participants have forgotten portions of the sequence.
It should be noted that MCI sample was not uniform. The high degree of instability in MCI classification can produce different neuropsychological profiles according to MCI subtypes (Summers & Saunders, 2012; Han & Kim, 2012). The sample of MCI patients was not stratified into different levels of severity, and as such it might not be

representative of the different clinical subgroups within this diagnostic category (see chapter one). The main reason for the lack of sample stratification was the relatively small sample size, which included only 20 patients. The MCI sample size was limited as the incidence of MCI that would lead participants to satisfy inclusion criteria is not particularly high. Often patients who require a neuropsychological investigation already exhibit severe cognitive difficulties or, on the contrary, have a subjective cognitive decline. In both cases they are not classified as MCI and were not included in the study. There are several clinical subtypes of mild cognitive impairment. MCI patients can be classified into three groups according to the impairment of cognitive functions as measured by a neuropsychological assessment: amnestic MCI if memory domain is impaired, multiple domains MCI which involves mild impairment in multiple cognitive domains with or without memory impairment (Petersen, 2003, 2004).

As only 20 patients were recruited over a period of six months, showing a range of different cognitive profiles, they were not categorised into specific MCI subtypes.

Some of them performed poorly in memory tests and other subjects show impairments in other cognitive functions (see Tables 8 and 9). Even if there is a strong emphasis on memory assessment for people at risk of developing dementia (Petersen et al. 2001), multi-domain MCI subtype is more frequent in individuals who show both visual and verbal deficits (Alladi et al., 2006). As is possible to observe in Table 4 and 5, MCI patients received an extensive neuropsychological assessment in order to investigate their cognitive functions and to receive the diagnosis made by neurologists in the following step. This was done to exclude subjects from the study that did meet the criteria of MCI. Data was analysed considering the 20 subjects as a unique group. Future studies should consider recruiting larger samples in order to obtain data that is more closely representative of the different clinical subtypes. The same consideration about how the heterogeneity of the MCI sample can affect the results of studies conducted with this type of patients was raised by Simon and colleagues (2012). They underlined the necessity to analyse each MCI subtypes separately because they can respond in a different way to cognitive tasks or interventions (Simon et al., 2012).

Taking into account the results from the total correct trials method of scoring, no difference was observed in the bootstrapping pattern as a consequence of cognitive difficulties in general. The beneficial impact of additional visual information was comparable for MCI and older participants, as evidenced by the lack of evidence for a group x display interaction. Immediate serial recall of digits seems to have been facilitated by adding spatial information in the display, both in MCI patients and older adults, suggesting the persistence of spatial bootstrapping across adult lifespan and in people with memory difficulties. The main effect of display type reflected that there were differences in memory performance across the two different conditions (single digit and typical keypad) and across the two groups. Specifically, there was a bootstrapping effect across the two groups. Performance in the keypad condition was significantly better than in the single digit condition. Furthermore, performance in the typical keypad condition was significantly higher than in the single item condition in both the older and MCI samples.

Considering the evidence from previous findings obtained by Darling et al. (2012, 2014) with children and younger adults and the study carried out with older people (see chapter three), it can be claimed that visuo-spatial bootstrapping seems to develop around nine years of age and tends to remain stable across the lifespan and in subjects who show mild cognitive impairments.

This pattern is in contrast with other cognitive changes which occur with the progression of age and in a condition of cognitive difficulties, such as MCI. It has been observed that MCI is associated with a stable pattern of specific deficits to working memory, language, attention, visual-spatial functions, executive function (Saunders & Summers, 2010, 2011, 2012; Belleville et al., 2007; Albert et al., 2011; Brant et al., 2009; Espinosa et al., 2009; Nordlund et al., 2005). Specifically, working memory declines in patients with MCI (Klekociuk et al., 2014; Cheng at al., 2008; Saunders & Summers, 2011; Belleville et al., 2011; Lopez, 2005), with a progressive working memory impairment from healthy ageing to degenerative disease (Belleville et al., 2007; Gagnon & Belleville, 2011) (see chapter one). Working memory is particularly impaired in MCI patients compared with cognitively normal older adults, showing difficulties to bind information (Brant et al., 2009; Kessel et al., 2010, Germano et al. 2008). These impairments can have an impact on everyday functioning (Aretouli & Brandt, 2010) causing difficulties completing tasks (Kimberg & Farah, 1993) and to produce appropriate response to the environment (Baddeley et al., 2001). Taking into account that both amnestic MCI and non-amnestic MCI display a remarkable impairment to spatial working memory, visual spatial span and complex sustained attention (Summers & Saunders, 2011; Klekociuk & Summers, 2014), no bootstrapping effect in MCI patients in this current study was expected to be found. Moreover, they show impairment to the central executive of working memory and difficulties to use appropriate strategies and rule acquisition (Summers & Saunders, 2011).

The findings from the current study seem to be not consistent with the data from the literature which describe a stable pattern of deficit to working memory (Klekociuk et al., 2014; Cheng at al., 2008; Saunders & Summers, 2011; Belleville et al., 2011; Lopez, 2005) and temporary binding (Logie, Parra, & DellaSala, 2015). It has been observed that patients in the early stages of Alzheimer's disease display difficulties in binding different aspects of a stimulus on a temporary basis (Logie, et al., 2009). They show impairments in tasks which require to temporary retain shapes and colours. On the contrary, temporary binding deficit appears to be preserved in healthy elderly subjects (Parra, Abrahams, et al., 2009; Parra, Della Sala et al., 2009).

These data are consistent with the conclusion of the irrelevant role of central executive in visuo-spatial bootstrapping effect observed in the study on central executive suppression (chapter two) and with the findings of study two on older adults (chapter three). Considering that visuo-spatial bootstrapping does not need to recruit central executive resources and MCI patients may have a specific impairment on CE, the positive findings on visuo-spatial bootstrapping effect in this population could be better understood. Moreover,the current findings seem to be in accordance with results that have been presented in a recent study on memory integration in amnesic patients using visuo-spatial bootstrapping task (Race et al., 2015). The capacity to integrate verbal information with stored visuo-spatial knowledge was found to be preserved in both amnesic patients and controls.

The results in the study carried out by Race and colleagues (2015) can offer an alternative perspective to understand the contrasting results obtained from the current study with MCI. In their study the sample was composed by patients with an isolated impairment in the domain of memory, with severe difficulty learning new information. The selected sample of MCI patients who entered the experimental study presented in this chapter was more heterogeneous. Some subjects performed poorly in memory tests whereas other participants showed impairments in other cognitive functions. Further investigations however need to be conducted in order to clarify the difference in results when using the two different scoring methods. Such studies would benefit from having groups of MCI patients subdivided according to different cognitive profiles.

In summary, it can be observed that visuo-spatial bootstrapping appears to be relatively consistent to cognitive decline, although the visuo-spatial and verbal memory systems may not be so robust. In this regard, it is important to note that in study two (chapter three), the significant difference in performance on the pre-test, between older adults and MCI, would suggest that this was the case, at least for verbal short term-memory. This data should be taken into account considering that these findings are observed in a paradigm whereby initial difficulty is set on a per-individual basis through the span pre-test.

Nonetheless, given that the benefit to performance by visuo-spatial bootstrapping seems robust against ageing and mild cognitive impairments, it can be considered a useful candidate for further research as understanding visuo-spatial bootstrapping may assist interventions to support individuals with mild cognitive difficulties. These findings could help to understand both cognitive and functional problems faced by MCI and support the identification of working memory impaired processes considering that patients with MCI have the risk seven times more to develop AD than older people without cognitive impairment (Boyle, Wilson, Aggarwal, Tanq, & Bennet, 2006) and 80% of them will progress to dementia after six year.

These surprising results can be beneficial in a context where there are no efficient treatments for patients with MCI (and AD) (Ritchie & Tokko, 2010; Callaway, 2012). It has been observed that pharmacological treatment for MCI and dementia seem to have only moderate effects on behaviour, cognition and function (Winblad et al., 2004). On the contrary, taking into account that there are some studies which show that cognitive interventions can have a positive effect with patients with MCI (Belleville et al., 2006; Kinsella, et al., 2009; Simon, et al, 2012; Unverzagt et al., 2007), visuo-spatial bootstrapping could be an useful paradigm to investigate as a potential tool of cognitive interventions. Although computerised training showed low generalisation both in patients with mild cognitive impairment (Clare et al., 2003) and in healthy older subjects (Owen et al., 2010), it can be an useful tool to use with those subjects. A computerised training model using visuo-spatial bootstrapping paradigm might produce positive results in teaching memory strategies considering the data obtained in the current study with elderly and MCI patients. Another possible application of visual-spatial bootstrapping as a tool for interventions is to combine implicit learning process with memory compensatory strategies (spaced retrieval, visual imagery and errorless learning for example) in order to train patients with MCI to learn new information (Scott & Spector, 2010). Further studies need to be done in order to test potential interventions to assist individuals with memory difficulties based on the visuo-spatial bootstrapping effect.

Furthermore, another intriguing line of investigation can be the exploration of the role of the central executive, replicating the study on central executive load in patients with MCI. Several studies indicate that best cognitive tests used as screening tests for predicting dementia in a non-demented person, involved executive control resources (Albert, Blacker, Moss, Tanzi, & McArdle, 2007; Albert, Moss, Tanzi, & Jones, 2001; Rapp & Reischies, 2005; Elias et al., 2000). It could also be interesting to investigate how central executive load could impact the performance on visuo-spatial bootstrapping in groups of older people and patients with dementia, who show a decrement of this function (Baddeley, 2002).

4.9 Conclusion

It has been observed that apparent contradictory results emerged from the analysis of the same data sets using the two different scoring methods. When results are scored with the proportion of individual correct items method, older adults and MCI patients show a small trend towards a benefit from familiar spatial information. On the contrary, using the total correct trial method of score, the bootstrapping effect was present in both older adults and patients with initial cognitive difficulties.

This current study showed surprising results as no difference was observed in the bootstrapping pattern as a consequence of cognitive difficulties. At the same time, substantial amount of studies seem to indicate that when required to combine two tasks, such as in the dual task test, normal elderly subjects showed a small tendency for performance to decline, whereas patients with Alzheimer’s disease (AD) performed with marked deficits (Baddeley et al., 1986). The impact of attentional control in patients with AD investigated with the dual task technique indicates a differential deficit in AD over and above that of ageing (Perry & Hodges, 1999). Further investigation with these populations, elderly people and patients in an early stage of cognitive deterioration, on visuospatial bootstrapping in articulatory suppression and executive load conditions could give new data and prospective about the role of working memory components.

CHAPTER 5

5.1 Discussion

The general purpose of the studies described in the present thesis was to investigate the structure of working memory, and in particular the relationship between verbal and visuo-spatial working memory. The main goal was to examine the role of display characteristics and spatial localisation in working memory. Specifically, this thesis aimed to determine the contribution of the central executive in younger and older adults and patients with Mild Cognitive Impairment of visuo-spatial bootstrapping paradigm (VSB; Darling & Havelka, 2010; Darling et al., 2012, 2014; Allen et al., 2015).

Visuo-spatial bootstrapping is as an effect that shows how visuo-spatial information can be used to support verbal memory and involves the integration of information from verbal and visuo-spatial short-term memory with long-term memory representations. (Visuo-spatial bootstrapping has been described in more depth in the chapter one, section on "Binding"). Research on bootstrapping has been introduced by Darling and Havelka (2010) observing that verbal recall of the digit sequences is more accurate when they are presented within a familiar array instead of single spatial location without any spatial information. Visual-spatial bootstrapping demonstrates that the type of display influences how well that information is retained. This current paradigm of visuo-spatial bootstrapping supports the more recent version of the multi component working memory model (Baddeley, Allen, & Hitch, 2011), which indicates that several different forms of information binding, such as visual, verbal and cross modal, can be automatically processed (Allen et al., 2006, 2014; Allen et al., 2012; Baddeley et al., 2009). Studies conducted using visual-spatial bootstrapping task show the presence of implicit cross-modality feature binding.

Working memory is important in several cognitive processes beyond simple memory tasks, including language learning (Baddeley, Gathercole & Papagno, 1998), navigation of the environment (Garden, Cornoldi & Logie, 2002), planning of activity (Law, Logie & Pearson, 2006) and many others. The multi component models of working memory

(Baddeley, 2000) encompass a broad array of processing and storage functions. According to this model, working memory is composed by the central executive and two sub systems, the phonological loop and the visuo-spatial sketchpad, which are passive stores that maintain information over short periods. Sub systems are thought to be distinct from each other with good evidence supporting their segregation (e.g. Smith, Jonides & Koeppe, 1996; Baddeley, Lewis & Vallar, 1984; Quinn & McConnell, 1996). However, when a stimulus fall in both domains, it needs to be encoded in both subsystems, but also link them together. In order to account for these processes, Baddeley (2000) proposed a new component of working memory, the episodic buffer. This limited capacity store is assumed to be recruited when information from different sources, including the working memory subsystems and long-term memory, has to be bound together and temporarily retained (e.g. Allen et al., 2006; Allen et al., 2009; Baddeley et al., 2009; Bao, et al., 2007; Karlsen et al., 2010).

Visuo-spatial bootstrapping requires interaction between verbal and visuo-spatial working memory without explicitly asking participants to bind information on a visually presented verbal digit recall task (Darling & Havelka, 2010). Research on visuo-spatial bootstrapping shows that memory for information presented visually for verbal serial recall is better when the visual display is arranged in a familiar spatially distributed pattern, i.e. a telephone keypad, in comparison to when the numbers are presented one after another in a single location. This improvement of memory performance through implicit bindings of visuo-spatial and verbal information looks to remain stable across cognitive development. It seems to facilitate performance in children from the age of nine (Darling et al., 2014) and young British adults (Darling et al., 2010, 2012).

5.1.1 General conclusion

The studies presented in this thesis demonstrated that visuo-spatial bootstrapping effect is also present in Scottish younger adults under cognitive load (chapter two), Italian young adults (see chapter three), older adults (Calia, Darling, Allen, Hevelka, 2015; see chapter three) and in people who start to have memory difficulties, such as patients with mild cognitive impairments (see chapter four). It appears to support recall of verbal information only when subjects have precedent knowledge of such associations. These data sets have been interpreted as being supportive of a notion that the episodic buffer plays a crucial role in integrating verbal and spatial information.

Moreover, in a previous study conducted by Allen and colleagues (2015), the role of both the phonological loop and visuo-spatial working memory in the bootstrapping task has been investigated. It has been observed that articulatory suppression during encoding impaired both single digit location and typical keypad display but with a greater impairment in the former. The articulatory suppression did not remove the bootstrapping effect. However, it has been noticed that the bootstrapping effect is removed under visuo-spatial suppression. Spatial tapping during encoding had a strong effect in both displays. This lead to the conclusion that bootstrapping integrates long-term memory trace with a visuo-spatial short-term memory trace (Allen et al., 2015).

In summary, from previous studies it becomes evident that the visuo-spatial bootstrapping requires access to relevant long-term memory representations. Which persists under phonological loop suppression but it is removed under visuo-spatial load and it is not observed in six years old but it is present in nine years olds and adults.

Having identified different characteristics involved in the visuo-spatial bootstrapping phenomenon, the aim of this thesis was to explore it in more detail in order to understand the role of central executive, and whether it persists in subjects who show working memory decline, such as older adults and patients with mild cognitive impairments.

5.1.2 Study 1

In the first study (chapter two) the role of the component of working memory that was not investigated previously in the visuo-spatial bootstrapping effect, the central executive, was explored. The investigation of the central executive is important, as it was argued by Baddeley (2000) that executive resources are required to support binding and integrative episodic buffer processes. This assertion has received some evidence (Brown & Brockmole, 2010; Elsley & Parmentier, 2009), although many forms of binding may in fact develop automatically, without requiring attention (e.g. Allen et al., 2006, 2009; Baddeley et al., 2010; Baddeley et al., 2009; Berlingeri et al., 2008; Karlsen et al., 2009; Rossi-Arnaud, Pieroni, & Baddeley, 2006). How central executive control is involved in integrating verbal and visuo-spatial information in this task was therefore important to be established.

For the study one, the dual-task paradigm was used, requiring to perform two tasks at the same time. The bootstrapping task, with digit sequences visually presented both in single or in a typical keypad display, was administered under conditions of verbal and central executive load. The articulatory suppression was used for this study as comparison task of the executive control load. This methodology was adopted in the previous study on visual bootstrapping demonstrating the use of familiar spatial distribution of information in boosting verbal memory under the articulatory suppression condition (Allen et al., 2015). Executive control load was implemented to examine how memory for digits presented within a familiar spatial configuration and in a single location can rely on executive functions. According to Baddeley (2000) and Elsley and Parmentier (2009) a substantial effect of central executive on performance was expected with no bootstrapping effect, considering that the bootstrapping task involved attention to stimuli in both conditions (single digit and typical keypad) and to the highly cognitive demanding concurrent task. This assumption is linked with the consideration that bootstrapping effect is based on multi-components and modality-independent working memory. A greater impact of central executive suppression both on the typical keypad condition and on the single digit display was expected to be found. However, no interaction could also be predicted, based on other recent work on binding (e.g. Baddeley et al., 2011) and on the assumption that the visuo-spatial bootstrapping effect is implicit.

The first study replicated once more the visuo-spatial bootstrapping effect (Allen et al., 2015; Darling & Havelka, 2010; Darling et al., 2012, 2014) as a consistent and reliable effect.

Central executive load had a substantial negative effect on digit recall performance in both typical keypad and single display condition, revealing an expected role of central executive in digit recall (Baddeley & Hitch, 1974). These results also demonstrate that the bootstrapping effect does not need to recruit phonological loop and executive resources or processes to function. These findings clearly demonstrate the marginal role of verbal and executive systems in combining information implicitly. Similar results were also obtained using the Bayesian ANOVA for both the analysis of total correct item method of score (TCT) and proportions correct item (PCI).

The data obtained from this study show that meaningful spatial information, such as a telephone keypad, facilitates verbal recall performance and reduces reliance during verbal memory tests on phonological system and central executive working memory. It has been demonstrated that bootstrapping can carry on even if phonological loop and central executive are loaded by a secondary task.

These findings are intriguing as they provide new insights for models of working memory and in particular the multi-component model by Baddeley (2000, 2007). The visuo-spatial bootstrapping effect then seems to support the role of the episodic buffer within the model of working memory by Baddeley (2000, 2007). This effect can be served by the episodic buffer which was described as a component that connects modality-specific components (visuo-spatial and verbal), central executive and long-term memory. At the same time this model is supported by research based on visuo-spatial bootstrapping which responds to different forms of concurrent disruption in a significant way. This indicates a dynamic relationship between cross-domain storage and specialised processing capacities, which demonstrates the flexible nature of working memory involving various processes that manage several different situations (Morey, 2009). These data sets can be linked with the modification of the conception of episodic buffer in recent years. It was initially described as being reliant on executive control (Baddeley, 2000), but then, with further studies, it has been proved that it is independent from attention and it can work automatically (Baddeley et al., 2011). The results from this study are in accordance to this perspective. At the same time, articulatory suppression and executive load display better the role of the episodic buffer bringing out the complex relation of sub components of working memory.

A similar pattern of results was obtained recently by Langerock and colleagues (2014) in their study of memory for visually presented verbal information, spatial locations, of verbal-spatial binding. They found that the role of attention is not crucial during the maintenance of verbal-spatial bindings in visual working memory. Their findings support the idea that in order to maintain verbal-spatial information there is no need of more attentional resources than for verbal or spatial features. Both processes are equally impaired by lack of maintenance of attention (Langerock et al., 2014). This observation is consistent with previous findings obtained by studies which investigated attention demanding between bindings between features and maintaining the features themselves (Allen et al., 2006; Morey & Bieler, 2013). Memory for features and memory for binding within the same modality (colour and shape) were disrupted in the same way by presence of an attention-demanding task and a secondary visual search task, including too, an auditory distraction (Allen et al., 2006; Morey & Bieler, 2013; Johnson, Hollingworth, & Luck, 2008). This line of research supports the idea that attentional demands do not affect binding between features (Langerock et al., 2014). The authors concluded hypothesizing that the difference in performance could be related to features of stimuli selected, with some of them familiar to participants, playing a relevant role in visual working memory. These observations concur with results obtained in the study one.

The novelty of the study one in comparison with all the other investigations on the role of central executive is that this time an implicit cross-modality features binding paradigm, such as visuo-spatial bootstrapping, was investigated. Central executive load demonstrated to have a considerable negative effect on digit recall performance in both displays condition, without affecting the bootstrapping effect. It can be concluded that the bootstrapping effect does not need to recruit executive resources.

5.1.3 Study 2

The aim of the second study (chapter three) was to investigate visuo-spatial bootstrapping in older adults compared to younger adults. This study originates from the idea to explore the bootstrapping effect in a population that generally show cognitive decline in many cognitive functions (Manan et al., 2013) including working memory. In fact, working memory seems to decline with age (Jost et al., 2011; Myerson et al., 2003; Chen et al., 2003). For this reason it has been thought to be a crucial concept for understanding cognitive and functional changes of older adults (Borella et al., 2009; Borella et al., 2008). Specifically, working memory binding seems to be particularly impaired in healthy ageing (Brockmole et al., 2008; Cowan et al., 2006; Mitchell et al., 2000; Parra et al., 2009) and appears to be not efficient as for younger adults (Maier et al., 2014). Considering the data emerging from the literature, the main reason to investigate visual-spatial bootstrapping in older adults was to investigate this paradigm across the lifespan, while attempting to understand other intriguing mechanisms of working memory and at the same time to add valuable data in the age-related research. Such an investigation had the potential to provide a theoretical basis for developing techniques to support older people remaining independent in their daily life for longer period of time. Cognitive training in healthy elderly subjects has been well explored teaching both theoretical strategies and skills to improve cognitive functions. These types of training can improve cognitive functions in elderly individuals (Ball et al., 2002; Stigsdotter & Backman, 1992) and seem to reduce the risk of cognitive impairments in this population (Valenzuela & Sachdev, 2009).

In this study two groups of young and older adults were recruited to compare their performances on visuo-spatial bootstrapping tasks, so that any lifespan related changes could be identified. In this way it was possible to observe how older people differ from young subjects in these tasks. Each participant was assessed with a brief neuropsychological battery of tests to ensure that participants were ageing with a typical cognitive profile. Then, they were tested across the display conditions at their maximum span for the single digit condition, which was assessed in a pre-test. In this study, the test of bootstrapping compared performance across three different conditions (instead of two, as the previous study suggests). A single digit display was contrasted with a typical keypad and a random keypad condition. In each trial participants tried to remember a random sequence of digits in 30 trials.

Administering the visuo-spatial bootstrapping paradigm for the first time in a sample of older adults showed that older adults displayed a comparable visuo-spatial bootstrapping effect to younger adults; performing better when digits were presented in a familiar keypad array. This leads to the conclusion that it is an effect that persists across the course of typical ageing. In both age groups performance in the keypad condition was significantly better than in the single digit and in the random keypad condition. Additionally, when simple main effects of display were assessed independently for each age group, there was a significant benefit for typical keypads in both groups. It has been demonstrated once more that the visuo-spatial bootstrapping required the availability of a familiar representation in long-term memory. No significant age differences were observed in the bootstrapping pattern. It seems that a stable consistent visuo-spatial bootstrapping effect is present through the lifespan. Moreover, in both age groups performance in the keypad condition was significantly better than in the single digit and in the random keypad conditions. This evidence supports the fact that visual-spatial bootstrapping required the availability of a familiar representation in long-term memory. These results are consistent with previous results in younger adults and older children (Darling et al, 2012; 2014).

Visuo-spatial bootstrapping seems to be a process that has a different and contrasting development from the other cognitive functions as it tends to remain stable across the lifespan. A consistent amount of studies demonstrated that several cognitive functions, and particularly working memory, decline with the progression of age (Babcock & Salthouse, 1990; Jost et al., 2011; Logie & Maylor, 2009; Myerson et al., 2003; Chen et al., 2003). Specifically, it has been observed that the decline in working memory generally starts in middle adulthood and becomes more visible in old age, around 60 years old (Craik & Salthouse, 2000; DeFrias et al., 2007; Li, et al., 2004; Park et al., 2000). The data gathered from the visual-spatial bootstrapping study also diverge from what the literature says about binding during the ageing period. Older people show difficulty to retain the associations between different features, while they perform normally in memory for separate components (Naveh-Benjamin & Kilb, 2014). They are less accurate on tests of shape-location binding (Borg, et al., 2011; Chalfonte & Johnson, 1996; Mitchell et al., 2000; Thoma et al., 2012). The performance in binding of verbal and spatial information found that older adults is not efficient as in younger adults (Meier et al., 2014). Visuo-spatial bootstrapping appears then to be relatively robust to cognitive decline, in contrast with the development of the other cognitive functions. This can be due to the observation that visual-spatial bootstrapping is automatically and implicitly linked to long-term memory, whereas other binding tasks do not require long-term binding.

Other information to take into account in order to better understand the visual-spatial bootstrapping effect is the ability to remember visual material by older people, a crucial component of this effect. It has been noted that this ability decreases with the progression of age (Reuter-Lorenz & Sylvester, 2005) and older adults show severe deficits in visuo-spatial working memory (Jenkins et al., 2000; Leonards et al., 2002; Kemps & Newson, 2006; Park et al., 2002). On the contrary, verbal working memory seems to be more robust than visuo-spatial working memory (Dang et al., 2012). A deficit of age-related binding can explain the decrements recognised across the adult lifespan in visual working memory (Brown & Brockmole, 2010). These observation can be linked with the declines over the course of normal ageing of fluid cognition (Horn & Cattell, 1967; Schaie, 2005). This can reflect that visuo-spatial bootstrapping can be a contribution from visuo-spatial long-term knowledge that can sustain the function of an otherwise declining visuo-spatial working memory. Overall, it seems that memory capacity declines with age, while the benefit of visuo-spatial bootstrapping effect appears to remain stable across the lifespan and it appears to be relatively robust to cognitive decline. However, it is important to note that these findings are observed in a paradigm whereby initial difficulty is set on a per-individual basis using a span pre-test. Therefore the underlying visuo-spatial and verbal memory systems may not be so robust. This can be noticed considering the significant difference in performance on the pre-test, at least for verbal short-term memory. In spite of these observations, given that the benefit of performance by visual-spatial bootstrapping seems robust against ageing, it can be considered a potentially fruitful candidate for further research based on interventions to assist individuals with age-related memory difficulties.

The literature on cognitive ageing and working memory that explains the cognitive difficulties faced by the older adults (Cabeza, 2001, 2002; Manan et al. 2013; Kemps & Newson, 2006; Bopp & Verhaeghen, 2005; Park et al., 2002) might seem to predict that visuo-spatial bootstrapping would decline over age too, but the present data is not consistent with this. As it was explained above, working memory appears to decline with age (Jost et al., 2011; Myerson et al., 2003; Chen et al., 2003) as well as the capacity in verbal and spatial binding (Meier et al., 2014). Specifically, older people show difficulty to retain the associations between different features (Naveh-Benjamin & Kilb, 2014) with severe deficits in visuo-spatial working memory (Jenkins et al., 2000; Leonards et al., 2002; Kemps & Newson, 2006; Park et al., 2002).

In order to understand this discrepancy, the HAROLD model (hemispheric asymmetry reduction in older age, Cabeza et al., 2002) and the STAC framework (Scaffolding Theory of Aging and Cognition, Park & Reuter-Lorenz, 2009) seem to offer interesting perspectives. Visuo-spatial bootstrapping may take advantage of a compensatory mechanism through a plastic reorganisation of neurocognitive networks and the engagement of scaffolding an adaptive neural response (Cabeza et al., 2002; Park & Reuter-Lorenz, 2009). According to these models for brain compensation, it can be hypothesised that visual-spatial bootstrapping can recruit new brain area (Cabeza, 2002; Reuter-Lorenz, 2002) in a plastic reorganisation of neurocognitive networks in order to maintain memory function. For example, older adults may utilise verbal working memory to maintain performance on skill learning tasks (Bo et al., 2012) as a consequence of relatively faster decline in visuo-spatial working memory. In typical young adults, brain activation is predominantly left lateralised for verbal working memory and right lateralised for visuo-spatial working memory, while older adults show more bilateral activation patterns for both types of memory (Reuter-Lorenz et al., 2000). Consequently, it might be expected that laterality patterns decrease and visuo-spatial working memory also declines with age. According to this view, it can be expected that older adults may use verbal memory strategies in visuo-spatial bootstrapping task. Similar outcomes can be predicted with the STAC model (Park & Reuter-Lorenz, 2009) that describes a process that involves development of alternative and complementary neural circuits to achieve a cognitive goal. According to the authors, this process seems to be present across the life span and it can be a potential interesting explanation of the findings obtained from the visuo-spatial bootstrapping studies.

5.1.4 Study 3

The aim of the third study (chapter four) was to examine performance on visuo-spatial bootstrapping task in a typical elderly sample compared with a sample of people with mild cognitive impairment (MCI, Petersen, 2004). This study can offer a contribution to the understanding of the mechanisms involved in the transition from a normal to a pathological ageing, which is a sensitive screening phase where interventions could be made. Mild cognitive impairment is a transitional stage between normal ageing and dementia which involves the onset and evolution of cognitive impairments beyond those expected based on the age and education of the individual, but which are not significant to interfere with daily activities (Petersen et al., 1999, 2001). It has been observed that working memory declines in patients with MCI (Brant et al. 2009; Cheng at al., 2008; Espinosa et al., 2009; Gagnon & Belleville, 2011; Klekociuk et al., 2014; Nordlund et al., 2005; Saunders & Summers, 2011, 2012; Belleville et al., 2011; Lopez, 2005), with progressive working memory difficulties from healthy ageing to degenerative disease (Belleville et al., 2007; Gagnon & Belleville, 2011). The relevance of working memory in the screening assessment for MCI patients was indicated in some studies which observed a reduced maintenance of bound information (Kessel et al., 2010, Germano et al. 2008).
In study three each participant was assessed with a brief neuropsychological battery of tests and the test of bootstrapping. However, an extensive neuropsychological assessment was undertaken for patients with MCI as part of a standard procedure to evaluate their cognitive profile (Mondini et al., 2011). In this study, the visual-spatial bootstrapping task was composed by a Single Digit display and a Typical Keypad condition with 15 trials each administered to both groups. Participants were tested across the two display conditions at their maximum span for the single digit condition, which was assessed in a pre-test.

The results emerged from the analysis of the same data sets using the two different scoring methods are apparently contradictory. Unlike the other two studies, using the proportional individual correct items method of scoring generated conflicting data in study three. The aim of both of them was to identify the level of accuracy of the sequences of digits. The total correct trials method of scoring verified if the sequence of digits was correct or not, while the proportion of individual correct items method calculated the proportion of items on any given trial recalled in the correct serial position. On the contrary, when results were scored with the proportion of individual correct items they did not seem to benefit from familiar spatial information. This could be explained considering that the latter method of scoring seems to incorporate more noise because it includes a mixture of successful and unsuccessful numbers in trials where participants have forgotten portions of the sequence. The strength of evidence for interactions between groups and display conditions was also able to be estimated using Morey & Rouder (2015) ANOVA BF function from the Bayes Factor package in R. This analysis showed that the proportion correct trials method of scoring showed less clear evidence than the total correct trial. However, it seems that both measures described the same pattern of results.

Taking into account the results from the total correct trials method of scoring, the main conclusion from study three is that the bootstrapping effect was present in both in MCI patients and older adults with no difference due to cognitive difficulties. The beneficial impact of additional visual information was comparable for MCI and older participants, suggesting the persistence of visuo-spatial bootstrapping across the life span of adult lifespan and in people with memory difficulties. This is evident by the lack of evidence for a group x display interaction.

Immediate serial recall of digits seems to have been facilitated by adding spatial information in the display, both in MCI patients and older adults. This suggests the persistence of visuo-spatial bootstrapping across adult lifespan and in people with memory difficulties. The main effect of display type reflected that there were differences in memory performance across the two different conditions and across the two groups.

This pattern of results is in contrast with other cognitive changes which occur with the progression of age and in a condition of cognitive difficulties, such as MCI. As it was described in chapter one, working memory is impaired in MCI patients (Klekociuk et al., 2014; Cheng at al., 2008; Saunders & Summers, 2011; Belleville et al., 2011; Lopez, 2005) compared with cognitively normal older adults, showing difficulties to bind information (Brant et al., 2009; Kessel et al., 2010, Germano et al. 2008). The findings from the current study also seem not to be consistent with the data from a recent study conducted by Logie and colleagues (2015) which show a temporary binding deficit in MCI patients. Specifically, it is interesting to link the results of the study three with the observation of a remarkable impairment to spatial working memory, visuo- spatial span and complex sustained attention in patients with a diagnosis of MCI (Summers & Saunders, 2011; Klekociuk & Summers, 2014). Those patients show impairment to the central executive of working memory and difficulties to use appropriate strategies and rule acquisition (Summers & Saunders, 2011). These impairments can affect every day functioning (Aretouli & Brandt, 2010) causing troubles completing tasks (Kimberg & Farah, 1993) and to produce appropriate responses to the environment (Baddeley et al., 2001).

The data obtained from study three are supported by the observation of central executive deficits in patients who develop dementia later (Baddeley et al., 1991; 1986; Brant et al., 2009; Summers & Saunders, 2011) and the conclusion of the irrelevant role of central executive in visual-spatial bootstrapping effect observed in the study on central executive suppression (chapter two). Considering that visual-spatial bootstrapping does not need to recruit central executive resources and MCI patients may have a specific impairment on it, the positive findings on visual-spatial bootstrapping effect in this population could be better understood. Moreover, the current findings seem to be in accordance with results that have been presented in a recent study on memory integration in amnesic patients using visual-spatial bootstrapping task (Race et al., 2015). The capacity to integrate verbal information with stored visuo-spatial knowledge was found to be preserved in both amnesic patients and controls. For this study the visuo-spatial bootstrapping paradigm was used, with digits presented in a familiar visuo-spatial display such as a typical keypad and with unfamiliar visuo-spatial display, like a random keypad. The results in the study carried out by Race and colleagues (2015) can offer an alternative perspective to understand the contrasting results obtained from the current study with MCI. In their study the sample was composed by patients with an isolated impairment in the domain of memory, with severe difficulty learning new information. In a different way, the sample of patients who entered the study three was more heterogeneous and was not stratified into different levels of severity and cognitive profile. It might not be representative of the different clinical subgroups within this diagnostic category (see chaper seven). MCI patients can be classified into three groups according to the impairment of cognitive functions: amnestic MCI if memory domain is impaired, multiple domains MCI which involves mild impairment in multiple cognitive domains with or without memory impairment (Petersen, 2003, 2004).

The main reason for the lack of sample stratification was the relatively small sample size, which included only 20 patients with different cognitive profile. According with Simon and colleagues (2012) the heterogeneity of the MCI sample can affect the results of studies conducted with this type of patients because they can respond in a different way to cognitive tasks or interventions. Future studies should consider recruiting larger samples of MCI patients subdivided according to different cognitive profiles. This should allow studies to obtain data that is more closely representative of the different clinical subtypes.

This beneficial effect on MCI and older adults can be explained through the compensatory mechanisms of a plastic reorganisation of neurocognitive networks as described by Cabeza and colleagues (2002) in their HAROLD model and by Park and Reuter-Lorenz (2009) in their STAC framework. The STAC framework considers the engagement of scaffolding an adaptive neural response that is used in the face of cognitive challenge throughout the life span, rather than a process specific to old age. These models for brain compensation could be a valid explanation about the preservation of memory functions through the activation and plastic reorganisation of brain area in MCI patients (Cabeza, 2002; Reuter-Lorenz, 2002; Simon et al., 2012). These models have already been used in support on positive results in studies on cognitive interventions with MCI patients (Belleville, Clement, Mellah, Gilbert, Fontane, & Gauhier, 2011; Hampstead, Stringer, Stilla, Deshpande, Hu, Bacon Moore, & Sathian, 2010). It has been observed increased activation and connectivity of several brain area and associated with memory training.

Another potential explanation of these findings is linked with the functions of the episodic buffer (Baddeley et al., 2011) that is resistant to ageing and maybe during initial cognitive difficulties, such as in patients with MCI. At the same time, these results can be explained throught the observation that visual-spatial bootstrapping effect seems to be automatic without the involvement of central executive resources (chapter two).

Considering that the benefit to performance by visuo-spatial bootstrapping seems robust against ageing and mild cognitive impairments, it can be considered a useful candidate for further research. Visual-spatial bootstrapping can be a fruitful candidate to assist interventions in order to support individuals with mild cognitive difficulties. Considering those patients have the risk seven times more to develop AD than older people without cognitive impairment (Boyle et al., 2006). These findings could, therefore, help to understand both cognitive and functional problems faced by MCI and support the identification of working memory impaired processes. These results can be beneficial in a context where there are no efficient treatment for patients with MCI (Ritchie & Tokko, 2010; Callaway, 2012). Pharmacological treatment for MCI and dementia seem to have only moderate effects on behaviour, cognition and function (Winblad et al., 2004). In a different way, it has been observed that cognitive interventions can have a positive effect with patients with MCI (Belleville et al., 2006; Kinsella et al., 2009; Simon et al., 2012; Unverzagt et al., 2007) and visual-spatial bootstrapping could be used as a potential tool. For example, a computerised training using visuo-spatial bootstrapping paradigm might produce positive results in teaching memory strategies. Further studies need to be done in order to test potential interventions to assist individuals with memory difficulties based on the visuo-spatial bootstrapping effect.

5.1.5 Implications to working memory models

The findings obtained from studies on visuo-spatial bootstrapping can have several implications to the models of working memory. First, they are compatible with the revised model of working memory by Baddeley (2000) which allows the possibility that long-term knowledge can facilitate encoding and retrieval when it is combined with the verbal memory information in the episodic buffer. This interpretation arose from the observation of better performance in the typical keypad condition that can be caused by integration of long-term knowledge about the familiar telephone keypad. The visuo-spatial bootstrapping effect seems to suggest that information held in different subcomponents of working memory can be linked together to improve performance on the verbal task and that information stored in long-term memory can be used to accomplish this achievement. This function was thought to be the role of the episodic buffer (Baddeley, 2000, Baddeley et al., 2011). As it was described in chapter one, binding in working memory was already described in many other studies, but the interaction between verbal and visuo-spatial working memory and long-term memory emerged for the first time on visuo-spatial bootstrapping studies (Darling et al., 2012). Participants attempt an explicitly verbal memory task without explicit visuo-spatial or long-term memory content. This methodology is different from most of the studies on binding which explicitly require binding between pairs of features held in working memory, such as remembering the shape and colour of a set of objects (Allen et al., 2006; Baddeley et al., 2009). The paradigm used in the bootstrapping investigated the role of the episodic buffer requiring implicit binding between pairs of features held in working memory. Research on visuo-spatial bootstrapping supports the role of the episodic buffer, which is a limited capacity store that maintain bound representations from different sources, including working memory subsystems and long-term memory in the absence of attention or executive input (Allen et al., 2006; Allen et al., 2009; Baddeley et al., 2009; 2011; Bao et al., 2007; Karlsen et al., 2010).

According to the multi modal working memory model (Baddeley et al., 2011), the episodic buffer is thought to be directly connected to modality-specific systems responsible for processing visual, spatial and phonological information. At the same time information from the environment access into the episodic buffer via these specialised systems. This general concept is supported by studies on visuo-spatial bootstrapping. For example, from the studies conducted by Allen and colleagues (2015) and the first one described in this thesis (chapter two) emerged that the bootstrapping effect responds in different ways to varying forms of concurrent disruption. This seems to suggest an interactive relationship between cross-domain storage and separable, specialised processing capacities. From the study conducted by Allen and colleagues (2015) articulatory suppression seems to impacts on the maintenance and rehearsal of familiar visually presented verbal material. In the typical keypad condition, the availability of familiar spatial distributions diminishes the reliance on verbal working memory, and as a consequence it reduced the impact of articulatory suppression. In a different way, articulatory suppression strongly affects the performance in the single digit condition. This is caused by the dependency on verbal maintenance, considering the absence of other visuo-spatial information. These findings, using the articulatory suppression in the study conducted by Allen and colleagues (2015) and the study described in chapter one, can be explained with the superior letter recognition memory under suppression (Morey, 2009). According to the theorisation raised by Morey (2009), the episodic buffer

(Baddeley, 2000) or the focus of attention (Cowan, 2005) are the components responsible to retain verbal-spatial associations.

In the same way to articulatory suppression, the central executive load had a substantial negative effect on both display conditions. However, the accessibility of familiar verbal-spatial patterns facilitates digit recall and reduces reliance on central executive resources and maintenance in verbal working memory. These findings contribute to the analysis on the role of attention and sub-systems, which might not support the interaction with stored knowledge in long-term memory. The executive resources seem not to be essential for visuo-spatial bootstrapping linking long-term memory and short-term memory information.

Once more, it is evident from the studies on visuo-spatial bootstrapping that it seems to support the role of the episodic buffer within the model of working memory by Baddeley (2000, 2007). While initially the episodic buffer was conceived to be reliant on executive control (Baddeley, 2000), recently it has been demonstrated that it can work automatically, being independent from attentional load (Baddeley et al., 2011). This data confirms this assumption.

It should be noted that, so far, most of the implications of the findings on the visuo-spatial bootstrapping paradigm have been addressed to the multimodal model of working memory as this effect may be served by the episodic buffer, which is a modality-general storage capacity within the multi-component model of working memory (Baddeley, 2000). This model of working memory is then supported by research on bootstrapping demonstrating interactive relationship between cross-domain storage and separable, specialised processing capacities. However, the results in this thesis are also potentially consistent with the embedded-process model of Cowan (2005) or the Controlled Attention Framework model by Engle (Engle, 2002; Engle et al., 1999; Kane & Engle, 2003) (see chapter one).

The model of Cowan is not inconsistent with the multimodal model of working memory, but they differ about the role of attention in handling bindings across features. Taking into account the role of the episodic buffer free from attentional involvement and on the contrary the fundamental role of attention postulated by Cowan, it seems that the results obtained from the studies on visuo-spatial bootstrapping tend to be in favour of the former position. In particular, through the study on executive load (chapter two) it has been noted that cross modal binding does not need to recruit attention. In the model of Cowan, the focus of attention covers a central role as it is a component of the activated subset of long-term memory and it is linked with the central executive processes. According to this perspective, information can be consciously noticed when attention is focused on one stimulus which activates long-term memory. As a consequence, information more readily available in working memory is the one under the focus of attention (Cowan, 1999). However, it has been demonstrated that the bootstrapping effect does not need to recruit executive resources as meaningful spatial information such as a telephone keypad facilitates verbal recall performance and that this process likely does not require executive resources. Another component to take into account to explain data of bootstrapping is the role of central executive in the model of Cowan (Cowan, 1988; Cowan et al., 2007). This component is always connected with long-term memory which activates items in the focus of attention, and with short-term retention. Short-term retention allows for focus on long term memory information under the focus of attention. As it is possible to note, this theorisation cannot explain the lack of reliance on central executive resources and maintenance in verbal working memory with the accessibility of familiar verbal-spatial patterns. Another component of the model of Cowan is the short-term storage which has a limited capacity and functions similarly for different kinds of information (for example phonological and visual). Essentially, this model does not consider separate systems in short-term memory (Cowan et al., 2007) as opposite of the multimodal model (Baddeley, 2003), in which the storage is described as modality-specific for visual and phonological information. Through the studies on visuo-spatial bootstrapping seems that information from different subcomponents of working memory are linked together to improve performance on the verbal task and that information stored in long-term memory is fundamental to accomplish this tasks. Moreover, the bootstrapping effect responds in different ways to varying forms of concurrent disruption suggesting an interactive relationship between cross-domain storage and separable, specialised processing capacities.

It can be concluded that findings from bootstrapping investigations do not support the unitary approach, such as the embedded-process model of Cowan (2005). Similarly, the controlled attention framework model by Engle (Engle, 2002; Engle et al., 1999; Kane & Engle, 2003) is an unitary model which cannot explain clearly the data from bootstrapping studies. For example, according to the controlled attention framework model, long-term memory requires executive control to retain and maintain representations into focus and at the same time attentional control is used to activate traces from long-term memory through controlled retrieval. However, it has been demonstrated that this is not the case considering the data from the executive load study on visuo-spatial bootstrapping as well from the findings of study two and three on older adults and MCI patients. According to Engle (2002) the ability of working memory is to use attentional control to maintain information relevant to the task despite distraction or interference. Also in this model the focus is on the role of attention. The ability of working memory does not refer to the memory itself, but to the ability to use attentional control to maintain information relevant to the task despite distraction or interference. A greater capacity of working memory is the result of the ability of attentional control (Engle, 2002). It has been argued that individual differences of working memory reflect the differences in the ability to control attention in order to keep the information active and easily retrievable, particularly in situations of distraction or interference. On the contrary, the data emerging from study one (chapter two) demonstrated the lack of central executive involvement in visuo-spatial bootstrapping. Even though overall performance decreases in the central executive load condition, the advantage of spatially distributed presentation is maintained. The role of executive functions seems to be not essential during implicit cross-modality features binding and this conclusion spreads light in working memory models for new stimulating interpretations.

In summary, from these three studies emerged intriguing results on visuo-spatial bootstrapping that give support to the initial investigation on children and younger adults (Darling et al., 2012, 2014); which can have potential useful implications to working memory models. The three different studies described in this thesis demonstrate that the visuo-spatial bootstrapping advantage is reliable. They also indicate that binding of verbal and spatial information is based on stored knowledge, as previous studies demonstrated (Allen et al., 2014; Darling et al., 2012, 2014; Darling & Havelka, 2010). The accessibility of familiar verbal-spatial patterns facilitates digit recall and at the same time, it does not add executive demand and maintenance in verbal working memory. It has been observed that the bootstrapping effect does not need to recruit the phonological loop (Allen et al., 2015) and executive resources and it is present in both in MCI patients and younger and older adults with no difference due to cognitive decline of ageing. Considering the evidence from previous findings obtained by Darling and colleagues (2012, 2014) with children and younger adults, it can be noticed that visuo-spatial bootstrapping seems to develop around nine years of age and tends to remain stable across the lifespan and in older adults and in subjects who show mild cognitive impairments.

In order to obtain this effect the visuo-spatial resources are essential to activated verbal-spatial associations during the encoding (Allen et al., 2015). However, when cross-modality binding are created within the episodic buffer, spatial resources become less crucial supporting the associations.

Considering the implications on working memory models, it can be concluded that the multimodal model of working memory seems to be supported by research on bootstrapping demonstrating interactive relationship between cross-domain storage and separable, specialised processing capacities. In addition this effect may be served by the episodic buffer (Baddeley, 2000). Other models, such as the embedded-process model of Cowan (2005) or the Controlled Attention Framework model by Engle (Engle, 2002; Engle et al., 1999; Kane & Engle, 2003) do not appear to account well for these new findings emerging from the investigations on visuo-spatial bootstrapping.

5.2 Future directions

While a substantial amount of research has significantly advanced our knowledge concerning how verbal and visuo-spatial information is temporarily stored in memory, many studies remain to be done; exploring how such information is integrated. Explaining the processing components involved in integrating information from different sources is a crucial issue in developing our understanding of working memory and cognitive function.

The visuo-spatial bootstrapping processes has the potential of developing a more sophisticated understanding of the structure of memory and cognition. At the same time, visuo-spatial bootstrapping can facilitate the development of applications of this effect. For example, the use of spatially distributed displays to facilitate learning and memory of complex information has a range of potentially useful applications.

Examining the cognitive processes underlying the visuo-spatial bootstrapping task could enable the development of clinical tools for assessing visuo-spatial and verbal integration in working memory. Moreover, focusing on the working memory model and the potential implications on it, the episodic buffer has proven to be a useful and productive component (Baddeley, 2000), but to date there is no adequate and straightforward tool to assess it. It is possible that the visuo-spatial bootstrapping paradigm may be helpful in meeting this challenge. An intriguing line of investigation can also be the exploration of the central executive, replicating the first study on central executive load in patients with MCI because it seems that the best cognitive task used as screening tests for predicting dementia involved executive control resources (Albert et al., 2001; 2007; Rapp & Reischies, 2005; Elias et al., 2000). Investigating how central executive load can impact the performance on visuo-spatial bootstrapping in groups of older people and patients with dementia, who show a decrement of this function, is another potential line of investigation (Baddeley, 2002). From the study on older adults and MCI patients (see chapter four) it is clear that the bootstrapping effect was present in both groups showing surprising results, as no difference was observed in the bootstrapping pattern as a consequence of cognitive difficulties. It seems that when it is required to combine two tasks, such as in the dual task methodology, normal elderly subjects showed a slight decline, whereas patients with Alzheimer's disease (AD) performed with marked deficits (Baddeley et al., 1986). The impact of attentional control in patients with AD, investigated with the dual task technique, indicates a differential deficit in AD over and above that of ageing (Perry & Hodges,1999). Further investigation, testing elderly people and patients in an early or advanced stage of cognitive deterioration, on visuo-spatial bootstrapping using articulatory suppression and executive load conditions could give new data and perspective about the role of working memory components.

Furthermore, taking into account the findings of the study by Langerock and colleagues (2014), it would be of value for future research to examine how visuo-spatial bootstrapping effects may vary across retention intervals. In fact, it can be useful to establish whether the bootstrapping benefit subsists or even increases over time. In this case it can be stimulating to explore what cognitive processes may be involved during these extended maintenance periods.

The examination of motor processing and eye movements during the bootstrapping task is likely to provide additional valuable insights and should be taken into consideration for further studies. Findings obtained from the study carried out by Smyth, Pearson and Pendleton (1988) on movement suppression tasks can contribute to investigate the relation between movements and performance in the bootstrapping task. Smyth and colleagues (1988) observed that subjects were able to remember familiar movement patterns while they performed a concurrent activity such as articulatory suppression and movement to external spatial targets. Memory for visually presented words and for sequences of spatial positions were not affected by movement suppression tasks. On the contrary, body-related movement are not affected by tasks which load memory for words and spatial positions (Smyth et al., 1988). These dissociations produce interesting implications for understanding the structure of working memory and memory for movements. Quinn and Ralston (1986) already emphasised the relevance of movement in spatial coding, but visuo-spatial processing implies other factors such as eye movements (Baddeley, 1983). Investigation on movments could offer new insight into the visuo-spatial bootstrapping paradigm.

Exploring the visuo-spatial bootstrapping through the compensatory mechanisms of a plastic reorganisation of neurocognitive networks as described by Cabeza and colleagues (2002) in their HAROLD model and by Park and Reuter-Lorenz (2009) in their STAC framework is another line of investigation about cerebral plasticity with many potential useful applications in the elderly population and in patients with cognitive difficulties. Visuo-spatial bootstrapping may take advantage of a compensatory mechanism through a plastic reorganisation of neurocognitive networks and the engagement of scaffolding an adaptive neural response (Cabeza et al., 2002; Park & Reuter-Lorenz, 2009). These models for brain compensation could be a valid explanation about the preservation of memory functions through the activation and plastic reorganisation of brain area in older adults and MCI patients (Cabeza, 2002; Reuter-Lorenz, 2002; Simon et al., 2012). As it was explained above, these models are also used to support positive results in studies on cognitive interventions with MCI patients (Belleville et al., 2011; Hampstead et al., 2010). Using fMRI before and after cognitive interventions, it has been observed that increased activation and connectivity of several brain areas in associations with memory training. Future research can be focused on understanding the mechanisms involved in the transition from a normal to a pathological ageing. Type of investigations have the potential to provide theoretical basis for developing techniques to support older people and patients who started to have cognitive difficulties to remain independent in their daily life for longer and inform best practices when working with this population. Moreover, the use of spatially distributed displays to facilitate learning and memory of complex information has a range of potentially useful applications especially in an ageing society with the incidence of neurodegenerative diseases on the rise. Considering the results of the studies presented in this dissertation, they can be beneficial in a context where there are no efficient treatments for patients with MCI (and AD) (Ritchie & Tokko, 2010; Callaway, 2012). To date, there are no effective pharmacological treatments for patients with MCI or dementia. Existing pharmacological therapies have only shown mild to moderate effects on behaviour, cognition and function (Winblad et al., 2004). On the contrary, some studies showed that cognitive interventions can have a positive effect with patients with MCI (Belleville et al., 2006; Kinsella et al., 2009; Simon et al, 2012; Unverzagt et al., 2007). Visuo-spatial bootstrapping could be an useful paradigm to investigate as a potential tool of cognitive interventions considering that also MCI patients seem to benefit from cognitive interventions (Simon et al., 2012). It has been observed the effects of these interventions have a variable duration depending on specific studies and combination of techniques (Belleville et al., 2006; Londos et al., 2008; Unverzagt et al., 2007). Although computerised training showed low generalisation both in patients with mild cognitive impairment (Clare et al., 2003) and in healthy older subjects (Owen et al., 2010). A computerised training using visuo-spatial bootstrapping paradigm might produce positive results in teaching memory strategies according to the results obtained in the study with elderly and MCI patients.

A new recent line of investigation in the development of neuropsychological assessment and treatment of memory deficits in older subjects is the virtual reality (VR) technology (Optale, Urgesi, Busato, Marin, Piron, Priftis, et al. 2010; García-Betances, Arredondo Waldmeyer, Fico & Cabrera-Umpiérrez, 2015; Rizzo, Schultheis, Kerns & Mateer, 2004). This approach has received consensus used in neuropsychological assessments and interventions for its ecological validity (Campbell, Zakzanis, Jovanovski, Joordens, Mraz & Graham, 2009; Lesk, Shamsuddin, Elizabeth, Walters & Ugail, 2014; Shah, Torres, Kannusamy, Chnq, He & Klainin- Yobas, 2015; Tarnanas, Schlee, Tsolaki, Müri, Mosimann, & Nef 2013; Parsons, 2015). Several studies ascertained the efficiency of VR supporting both patients in the early stages of dementia and their family by giving educational support and memory assistance (Cotelli, Manenti, Zanetti, & Miniussi, 2012; García-Betances, Jiménez-Mixco, Arredondo & Cabrera- Umpiérrez, 2014; Gregg & Tarrier, 2007; Man, Chung, & Lee, 2012). To date several research have focused on specific aspects of cognitive impairments in AD using virtual reality as a diagnostic and training tool. A good summary of the relevant studies have been described in the mini-review by García-Betances, Arredondo Waldmeyer, Fico and Cabrera-Umpiérrez (2015). The authors reported for each cognitive functions investigated, such as attention, memory, executive functions etc., the main studies using virtual reality.

At the same time, VR seems to be a valid tool for memory training in subjects with MCI (Man et al., 2012; Plancher, Tirard, Gyselinck, Nicolas, & Piolino, 2012; Weniger, Ruhleder, Lange, Wolf, & Irl, 2011). Taking into account this promising new data, a potential speculation about a possible application of visuo-spatial bootstrapping is to be adopted by virtual reality technology as it can assist verbal memory processes. Visual-spatial bootstrapping supports the existence of processes that can integrate information held in long-term memory with short-term visuo-spatial memory for sequences of locations and short-term verbal memory for sequences of digits. It can offer benefits of linkages between different kinds of information in short-term memory that can find a practical application in a virtual reality assessments and interventions. This suggestion about potential application of visual-spatial bootstrapping paradigm applied to virtual reality needs to be investigated.

Another clinical population that could reveal interesting information administering the visuo-spatial bootstrapping task is patients with multiple sclerosis (MS). Around 70% of patients who received a diagnosis of MS show cognitive impairments in working memory, executive functions, verbal fluency, memory and attention (see Brochet, 2011; Chiaravallotti & De Luca, 2008). Those impairments impact significantly the functional activities and quality of life in those patients. In particular, impairments in working memory seem to affect more the central executive than the sub systems in relation to the model of Baddeley (Lengenfelder, Chiaravallotti, Ricker, & DeLuca, 2003; Litvan, Grafman, Vendrell, & Martinez, 1988). Considering that the central executive seems to not play relevant role integrating information implicitly, it can be expected to find visuo-spatial bootstrapping effect in patients with multiple sclerosis. This could reinforce findings already obtained about visual-spatial bootstrapping and can be potentially translated in cognitive rehabilitation interventions. To date, there are no effective pharmacological treatments and cognitive interventions, despite the evident need for support for person with multiple sclerosis, considering the incisive effects of those impairments in their life and the cost of MS to society (De Luca & Chiaravallotti, 2011).

5.3 Conclusion

These three studies provided valuable insight on visuo-spatial bootstrapping which give support to the initial investigations on children and younger adults (Darling & Havelka, 2010; Darling et al., 2012, 2014; Allen et al., 2014). The three experimental studies demonstrated that the visuo-spatial bootstrapping advantage is an highly reliable construct, it does not require to recruit executive resources and it is present in both MCI patients, along with younger and older adults with no difference due to cognitive decline of ageing. In conclusion, visuo-spatial bootstrapping seems to develop around nine years of age and tends to remain stable across the lifespan of older adults and in subjects who show mild cognitive impairments.

The multimodal model of working memory seems to be supported by research on bootstrapping demonstrating interactive relationship between cross-domain storage and separable, specialised processing capacities. In addition this effect may be served by the episodic buffer (Baddeley, 2000).

All of those investigations could provide important implications for models of human memory and aid development of potential practical applications across a wide range of settings including technological interface usability, memory rehabilitation, and clinical tools for assessing components of working memory as it has been hypothesised. This line of research not only addresses critical and timely questions concerning our understanding of human memory, but also has the clear potential to feed through to a wide range of practical applications. Increasing the understanding of working memory functioning through this type of research opens up an opportunity to test potential interventions to assist individuals with memory difficulties based on the visuo-spatial bootstrapping effect. Additionally it will allow for the development of rehabilitation strategies and mnemonic techniques that will enable people with memory deficits to improve their performance by learning how to increase reliance on intact working memory components to compensate for other, underperforming, components. These techniques will be of benefit not only to neuropsychological patients but also to other groups (e.g. older adults) that tend to have difficulties in remembering information. The use of spatially distributed displays to facilitate learning and memory of complex information has a range of potentially useful applications. Especially in an ageing society with a number of neurodegenerative diseases on the rise.

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APPENDICES

APPENDIX 1

STUDY 1

Visuo-spatial bootstrapping (VSB) and the contribution of subcomponents of working memory: Central Executive suppression

Materials

Queen Margaret University

EDINBURGH

Information Sheet for Participants

My name is Clara Calia and I am a PhD student from the School of of Arts, Social Sciences and Management, Division of Psychology and Sociology, at Queen Margaret University in Edinburgh. As part of my research degree course, I am undertaking a research study entitled Remembering numbers: researching memory in younger adults.

The study is concerned with memory. Memory is not just one thing because there are different types of memory. In this research it will be investigate working memory (WM), a cognitive mechanism that can be regarded as the "workbench" of our mind. We rely on WM whenever we need to activate and retain information over short periods of time. It is involved in a range of everyday tasks and behaviours from language learning to navigation of the environment.

This research is being funded by Queen Margaret University, located in Edinburgh, Scotland.

I am looking for volunteers to participate in the project. You have been asked because you are in a range of age between 19 to 35 years old, native English speaker.

If you agree to participate in the study, you will be asked to remember a sequence of digits for few seconds as a computerised test to assess working memory. There are no known benefits or risks for you in this study. The whole procedure should take no longer than 1 hour. You will be free to withdraw from the study at any stage and you would not have to give a reason.

All data will be anonymised as much as possible. When data will be recorded participant number will be used instead of your name., and it will not be possible for you to be identified in any reporting of the data gathered.

Your responses to this experiment will be recorded to assess accuracy later. All recordings will be stored confidentially

The results may be published in a journal or presented at a conference.

If you would like to contact an independent person, who knows about this project but is not involved in it, you are welcome to contact Dr Stuart Wilson. His contact details are given below.

If you have read and understood this information sheet, any questions you had have been answered, and you would like to be a participant in the study, please now see the consent form.

Contact details of the researcher

Name of researcher: Clara Calia

Address: Postgraduate Student,
School of of Arts, Social Sciences and Management,
Division of Psychology and Sociology
Queen Margaret University, Edinburgh
Queen Margaret University Drive
Musselburgh
East Lothian EH21 6UU

Email: ccalia@qmu.ac.uk / 0131 474 0000

Contact details of the independent adviser

Name of adviser: Dr Stuart Wilson

Address: Lecture in Psychology,
School of of Arts, Social Sciences and Management,
Division of Psychology and Sociology
Queen Margaret University, Edinburgh
Queen Margaret University Drive
Musselburgh
East Lothian EH21 6UU

Email / Telephone: swilson@qmu.ac.uk / 0131 474 0000

Queen Margaret University

EDINBURGH

Participant Consent Form

Title of the project: Visuospatial Boostrapping in younger adults

I have read and understood the information sheet and this consent form. I have had an opportunity to ask questions about my participation.

I understand that I am under no obligation to take part in this study.
I understand that I have the right to withdraw from this study at any stage without giving any reason.
I understand that I may leave out any answers to any item without having to give a reason.
I understand that my responses will be audio recorded.

I agree to participate in this study.

Name of the participant:___________________________
Signature of participant:__________________________
Signature of Researcher:__________________________
Date:____________

Contact details of the researcher

Name of researcher: Clara Calia
email address: ccalia@qmu.ac.uk
Address: Clara Calia.
School of Arts, Social Sciences and Management
Division of Psychology and Sociology
Queen Margaret University Edinburgh, EH21 6U

Queen Margaret University

EDINBURGH

Instructions

I Condition

In these trials you will see a sequence of numbers that you have to remember.
Before seeing the sequence of numbers, a message will appear on the screen, asking you to say the days of the week or the months of the year starting from a random day or month.
You should try to remember as many numbers as you can while saying the sequence verbally.

Example:
- Please say the days of the week or the months of the year beginning with "Wednesday". Begin now…
You have to start saying: Wednesday, Thursday, Friday, Saturday, Sunday, Monday, etc….

- Or it could be: Please say the days of the week or the months of the year beginning with "April"
You have to start saying: April, May, June, July, August, September, etc…

Please continue saying the days of the week or months of the year until the sequence of numbers stops.

In the meantime the numbers will appear on the screen and you have to memorize them. When the numbers disappear, you have to stop saying the days of the week or the months of the year and say the sequence of numbers aloud so that the experimenter can write them down.

Queen Margaret University

EDINBURGH

Instructions

II Condition

In these trials you will see a sequence of numbers that you have to remember.
Before seeing the sequence of numbers, a message will appear on the screen, asking you to say the days of the week mixed with the months of the year. You should try to remember as many numbers as you can while saying the sequence verbally.

Example:
- Please say the days of the week and the months of the year beginning with "Wednesday- April". Begin now…
You have to start saying: Wednesday- April, Thursday- May, Friday- June, Saturday- July, Sunday- August, Monday- September, etc….

- Or it could be: Please say the days of the week or the months of the year beginning with "Saturday- January"
You have to start saying: Saturday- January, Sunday- February, Monday-March, Tuesday- April, Wednesday- May, etc…

In the meantime the numbers will appear on the screen and you have to memorize them. When the numbers disappear, you have to stop saying the days of the week and the months of the year and say the sequence of numbers aloud so that the experimenter can write them down.

EXPERIMENT 1

P NUM________ Sex______________ Education _________________

Age______________________ PPT date__________________________

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EXPERIMENT 1

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Age______________________ PPT date___________________________

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EXPERIMENT 1

P NUM________ Sex______________ Education _________________

Age______________________ PPT date__________________________

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EXPERIMENT 1

P NUM________ Sex______________ Education_________________

Age______________________ PPT date___________________________

Condition EC TYPICAL Span ____________________________

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Queen Margaret University

EDINBURGH

Debriefing Statement

Thank you so much for participating in this study. Your participation was very valuable to us. We know you are very busy and very much appreciate the time you devoted to participating in this study.
There was some information about the study that we were not able to discuss with you prior to the study, because doing so probably would have impacted your actions and thus skewed the study results. I would like to explain these things to you now.

In this study, we were interested in understanding memory, in particular working memory (WM). We rely on WM whenever we need to activate and retain information over short periods of time. It is involved in a range of everyday tasks and behaviours from language learning to navigation of the environment. Based on prior research, we expect to find that information that is presented visually for verbal serial recall is recalled better when the visual display is arranged in a familiar spatially distributed pattern, such as a telephone keypad.
The two conditions (Single Display and Typical Keypad) were administered three times in order to explore how separable processing capacities might each contribute to a better recall, by examining the disruptive impacts of verbal and executive concurrent tasks that you were presented with.

We hope this clarifies the purpose of the research. If you would like more information about state the topic of the study, you may be interested in the following:

- Darling, S. and Havelka, J. (2010). Visuospatial bootstrapping: Evidence for binding of verbal and spatial information in working memory, *The Quarterly Journal of Experimental Psychology.*
- Darling, S., Allen, R. J., Havelka, J., Campbell, A. and Rattray, E. (2012). Visuospatial bootstrapping: Long-term memory representations are necessary for implicit binding of verbal and visuospatial working memory. *Psychon Bull Rev.*
- Darling, S., Parker, M.J., Goodall, K.E., Havelka, J. and Allen, R. (2013). Visuospatial bootstrapping: Implicit binding of verbal working memory to visuospatial representations in children and adults. *Journal of Experimental Child Psychology*.

It is very important that you do not discuss this study with anyone else until the study is complete. Our efforts will be greatly compromised if participants come into this study knowing what is about and how the ideas are being tested.

If you have any questions or concerns, please ask me now, or you may contact contact the research supervisor Dr Stephen Darling at 0044 (0) 131 474 0000. email: sdarling@qmu.ac.uk.

Alternatively, contact the independent adviser whose details are found on the information sheet you received at the start of the study.

Thank you again for your participation!

Contact details of the researcher

Name of researcher: Clara Calia

Address: Postgraduate Student,
School of of Arts, Social Sciences and Management,
Division of Psychology and Sociology
Queen Margaret University, Edinburgh
Queen Margaret University Drive
Musselburgh
East Lothian EH21 6UU

Email: ccalia@qmu.ac.uk / 0131 474 0000

Contact details of the independent adviser

Name of adviser: Dr Stuart Wilson

Address: Lecture in Psychology,
School of of Arts, Social Sciences and Management,
Division of Psychology and Sociology
Queen Margaret University, Edinburgh
Queen Margaret University Drive
Musselburgh
East Lothian EH21 6UU

Email / Telephone: swilson@qmu.ac.uk / 0131 474 0000

APPENDIX 2

Study 2

Visuo-spatial bootstrapping (VSB) in older and younger adults

Materials

Queen Margaret University

EDINBURGH

Scheda di informazioni per i partecipanti

Il mio nome è Clara Calia, sono una dottoranda presso la Scuola di Arte, Scienze Sociali e Managment, Divisione di Psicologia e Sociologia, presso l'Università Queen Margaret di Edimburgo. Come parte del mio dottorato, sto avviando un progetto di ricerca il cui titolo è: Ricordare i numeri: comprendere la memoria negli anziani e nei giovani

Lo scopo di questa ricerca è quello di comprendere alcuni meccanismi della memoria. La memoria non è un singola funzione unitaria, ma ci sono diversi tipi di memoria che utilizziamo. In questa ricerca mi occuperò specificatamente della memoria di lavoro (MdL) che è un meccanismo cognitivo che permette l'immagazzinamento temporaneo e la prima manipolazione dell'informazione. Ci affidiamo alla MdL ogni volta che abbiamo bisogno di attivare e conservare le informazioni per brevi periodi di tempo. E 'implicata in una serie di attività quotidiane e di comportamenti, dall'apprendimento di una lingua alla navigazione dell'ambiente.

Questa ricerca è stato finanziata dall'Università Queen Margaret, che si trova ad Edimburgo, in Scozia.

Le è stato chiesto di partecipare come volontario al progetto perché è in una fascia d'età tra 20 e 35 o tra 55 e 75 anni.

Se accetta di partecipare allo studio, le verrà chiesto di fare una breve serie di semplici test di memoria e di altre misure cognitive, come ad esempio un test computerizzato per valutare la memoria di lavoro. Non sono noti i benefici o rischi per lei in questo studio. L'intera procedura non dovrebbe richiedere più di 1 ora. E' libero/o di ritirarsi dallo studio in qualsiasi momento senza dover dare una spiegazione.

Tutti i dati raccolti rimarranno anonimi. Quando i dati saranno registrati il suo nome sarà sostituito da un numero assegnato ad ogni partecipante, e non sarà possibile poter essere identificati.

I risultati potranno essere pubblicati su una rivista o presentati in una conferenza.

Se si desidera contattare una persona indipendente, che sa di questo progetto, ma non è coinvolta in esso, potrà contattare il Dottor Stuart Wilson. Di seguito troverà i suoi contatti.

Se ha letto e compreso questo foglio informativo, se le sue domande hanno ricevuto risposta e vorrebbe partecipare allo studio, può leggere il modulo del consenso informato.

Contatti dei ricercatori

Nome del ricercatore: Clara Calia

Indirizzo: Dottoranda presso
Scuola di Arte, Scienze Sociali e Managment,
Divisione di Psicologia e Sociologia
Queen Margaret University, Edimburgo
Queen Margaret University Drive
Musselburgh
East Lothian EH21 6UU

E-mail: ccalia@qmu.ac.uk / 0131 474 0000

Contatti del consulente indipendente

Nome del consulente: Dr Stuart Wilson

Indirizzo: Professore in Psicologia,
Scuola di Arte, Scienze Sociali e Managment,
Divisione di Psicologia e Sociologia
Queen Margaret University, Edimburgo
Queen Margaret University Drive
Musselburgh
East Lothian EH21 6UU

E-mail / Telefono: swilson@qmu.ac.uk / 0131 474 0000

Queen Margaret University

EDINBURGH

Consenso informato

Titolo del progetto: la memoria visuospaziale negli adulti e nei giovani

Dichiaro di aver letto e compreso il foglio informativo ed il modulo di consenso. Ho avuto l'opportunità di fare domande sulla mia partecipazione.

Ho capito che io non ho l'obbligo di prendere parte a questo studio.
Sono consapevole che ho il diritto di recedere dal presente studio in qualsiasi momento senza dare alcuna motivazione.
Sono consapevole che posso non rispondere alle domande senza dover dare alcuna spiegazione.

Accetto di partecipare a questo studio.

Nome del partecipante:________________________
Firma del partecipante:________________________
Firma del ricercatore:_________________________
Data:____________

Contatti del ricercatore
Nome del ricercatore: Clara Calia
indirizzo e-mail: ccalia@qmu.ac.uk

Indirizzo: Clara Calia
School of Arts, Social Sciences and Management
Division of Psychology and Sociology
Queen Margaret University Edinburgh, EH21 6UU

DATA SHEET

Participant number		Education	
Date of Birth		Date	
Age			

	P.G.	**P.C.**	**P.E.**
Screening			
Raven's Matrices			
MMSE			
Memory			
Digit Span forward			
Digit Span backward			
Corsi Block Tapping test			
VPT			
Bootstrapping test			

Medical history:

____

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____

Pharmacotherapy:

____

____

MINI MENTAL STATE EVALUATION (M. M. S. E.)

Nome______________________________________Cognome_____________

Data___/_______/_______ Test Somministrabile SI ☐ NO☐

*In che anno siamo? (0-1)*____ ☐

*In che stagione siamo? (0-1)*____ ☐

*In che mese siamo? (0-1)*____ ☐

*Mi dica la data di oggi? (0-1)*____ ☐

*Che giorno della settimana è oggi? (0-1)*_____________________________________ ☐

*Mi dica in che Nazione siamo? (0-1)*____ ☐

In quale regione italiana siamo? (0-1) _____________________________________ ☐

In quale città ci troviamo? (0-1) _____________________________________ ☐

Mi dica il nome del luogo dove ci troviamo? (0-1) ____________________________ ☐

*A che piano siamo? (0-1*____ ☐

Far ripetere: "pane, casa, gatto". La prima ripetizione dà adito al punteggio.

*Ripetere finchè il soggetto esegue correttamente, max 6 volte (0-3)*_________________ ☐

*Far contare a ritroso da 100 togliendo 7 per cinque volte*__________________________ ☐

93 ☐ 86 ☐ 79 ☐ 72 ☐ 65 ☐

*(se non completa questa prova, allora far sillabare all'indietro la parola M O N D O) (0-5)*_____________
____ ☐

☐ ☐ ☐ ☐ ☐

O D N O M

*Chiedere la ripetizione dei tre soggetti precedenti (0-3)*__________________________ ☐

*Mostrare un orologio ed una matita chiedendo di dirne il nome (0-2)*________________ ☐

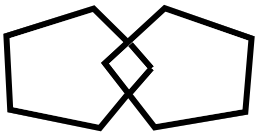
*Ripeta questa frase: "TIGRE CONTRO TIGRE" (0-1)*___________________________

Prenda questo foglio con la mano destra, lo pieghi e lo metta sul tavolo (0-3) _______

*Legga ed esegua quanto scritto su questo foglio (chiuda gli occhi) (0-1)*_______

*Scriva una frase (deve contenere soggetto e verbo) (0-1)*_________________________

*Copi questo disegno (pentagoni intrecciati) (0-1)*_______________________________

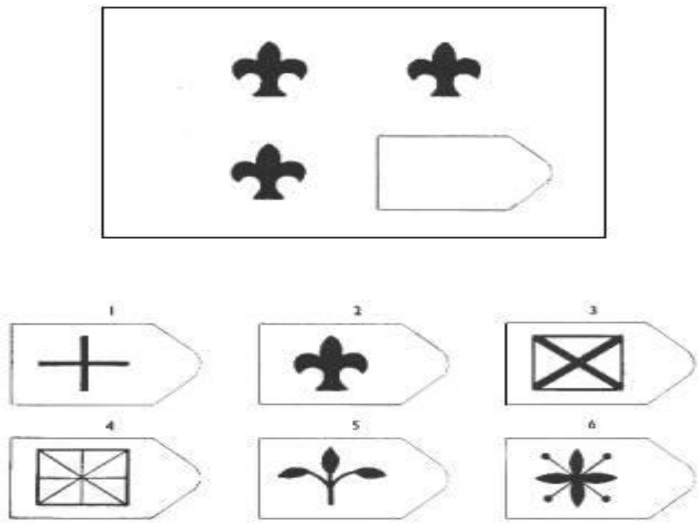


Digit Span forward and backward

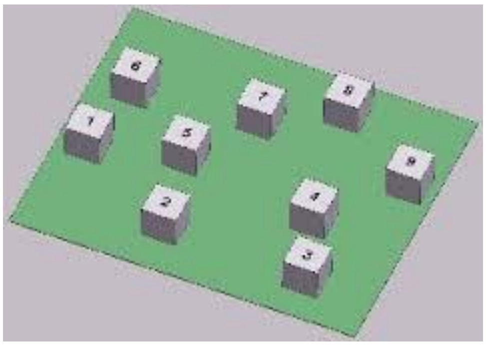
2 4	3 6
5 8 2	6 9 4
6 4 3 9	7 2 8 6
4 2 7 3 1	7 5 8 3 6
6 1 9 4 7 3	3 9 2 4 8 6
5 9 1 7 4 2 8	4 1 7 9 3 8 6
5 8 1 9 2 6 4 7	3 8 2 9 5 1 7 4
2 7 5 8 6 2 5 8 4	7 1 3 9 4 2 5 6 8
Forward:	
Backward:	

Raven's Coloured Progressive Matrices

Example of test items

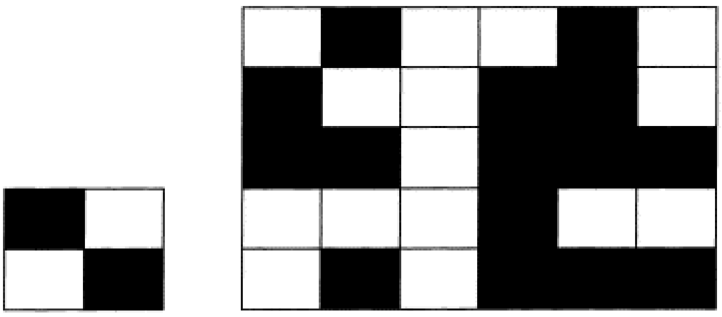


Corsi Block Tapping test



Visual Patterns Test (VPT)

Example of the test items



EXPERIMENT 2

P NUM________ Sex______________ _________________

Age_______________________ PPT date___________________________

Condition Single digit Span____________________________

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EXPERIMENT 2

P NUM________ Sex______________ _________________

Age_______________________ PPT date___________________________

Condition Typical Keypad Span____________________________

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EXPERIMENT 2

P NUM________ Sex______________ ________________

Age______________________ PPT date___________________________

Condition Random Keypad Span____________________________

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Queen Margaret University
EDINBURGH

Debriefing

Grazie mille per aver partecipato a questo studio. La sua partecipazione è stata molto importante. So che lei è molto occupata/o e apprezzo molto il tempo che ha dedicato a partecipare a questo studio.

Ci sono alcune informazioni sullo studio che non sono stata in grado di discuterne prima con lei, perché così facendo, probabilmente avrebbe alterato le sue azioni e quindi distorto i risultati dello studio. Vorrei potergliele spiegare adesso.

In questo studio sono interessata a comprendere come funziona la memoria, in particolare memoria di lavoro (MdL). Noi facciamo affidamento alla MdL ogni volta che abbiamo bisogno di attivare e conservare le informazioni per brevi periodi di tempo. Ci affidiamo alla MdL ogni volta che abbiamo bisogno di attivare e conservare le informazioni per brevi periodi di tempo. E 'implicata in una serie di attività quotidiane e di comportamenti, dall'apprendimento di una lingua alla navigazione dell'ambiente. Sulla base di ricerche precedenti, mi aspetto di trovare che l'informazione verbale che viene presentata visivamente viene ricordata meglio quando la visualizzazione è disposta in un modello familiare spazialmente distribuito, ad esempio una tastiera telefonica.

Mi auguro che questo chiarisce lo scopo della ricerca. Se si desidera approfondire l'argomento potrà trovare ulteriori informazioni sulle ultime due ricerche pubblicate:

-Darling, Stephen & Allen, Richard J. & Havelka, Jelena & Campbell, Aileen & Rattray, Emma (2012). Visuospatial bootstrapping: Long-term memory representations are necessary for implicit binding of verbal and visuospatial working memory. *Psychon Bull Rev*

- Darling, Stephen and Havelka, Jelena (2009) 'Visuospatial bootstrapping: Evidence for binding of verbal and spatial information in working memory', *The Quarterly Journal of Experimental Psychology.*

E 'molto importante che lei non discuta di questo studio con nessuno fino a quando non è stato completato. I nostri sforzi saranno compromessi se i partecipanti partecipano allo studio sapendo di che cosa si tratta in quanto queste ipotesi sono in fase di sperimentazione.

Se ha domande o dubbi, può chiedermi informazioni ora, o può contattare il Dr Stephen Darling, supervisore della ricerca, al 0044 (0) 131 474 0000. e-mail: sdarling@qmu.ac.uk. In alternativa, può decidere di contattare il ricercatore indipendente i cui dettagli sono indicati sul foglio informativo che le è stato consegnato all'inizio della ricerca.
Grazie ancora per la sua partecipazione!

APPENDIX 3

Study 3

Visuo-spatial bootstrapping (VSB) in older adults and patients with Mild Cognitive Impairment (MCI)

Materials

Queen Margaret University

EDINBURGH

Scheda di informazioni per i partecipanti

Il mio nome è Clara Calia, sono una dottoranda presso la Scuola di Arte, Scienze Sociali e Managment, Divisione di Psicologia e Sociologia, presso l'Università Queen Margaret di Edimburgo. Come parte del mio dottorato, sto avviando un progetto di ricerca il cui titolo è: "Memoria di numeri".

Lo scopo di questa ricerca è quello di comprendere alcuni meccanismi della memoria. La memoria non è un singola funzione unitaria, ma ci sono diversi tipi di memoria che utilizziamo. In questa ricerca mi occuperò specificatamente della memoria di lavoro (MdL) che è un meccanismo cognitivo che permette l'immagazzinamento temporaneo e la prima manipolazione dell'informazione. Ci affidiamo alla MdL ogni volta che abbiamo bisogno di attivare e conservare le informazioni per brevi periodi di tempo. E 'implicata in una serie di attività quotidiane e di comportamenti, dall'apprendimento di una lingua alla navigazione dell'ambiente.

Questa ricerca è stato finanziata dall'Università Queen Margaret, che si trova ad Edimburgo, in Scozia.

Io sto reclutando volontari per questo progetto di ricerca.

Se accetta di partecipare allo studio, le verrà chiesto di fare una breve serie di semplici test di memoria e di altre misure cognitive, come ad esempio un test computerizzato per valutare la memoria di lavoro. Non sono noti i benefici o rischi per lei in questo studio.

L'intera procedura non dovrebbe richiedere più di 1 ora e sarà divisa in 2 sessioni. E' libero/o di ritirarsi dallo studio in qualsiasi momento senza dover dare una spiegazione. Inoltre potrà decidere di non rispondere alle domande che vorrà in qualsiasi momento.

Questa ricerca è estranea a qualsiasi trattamento medico in corso - non la aiuterà personalmente e non è una parte del trattamento. Inoltre, se sceglie di non partecipare, questa decisione non avrà alcun effetto sul suo trattamento medico.

Tutti i dati raccolti rimarranno anonimi. Quando i dati saranno registrati il suo nome sarà sostituito da un numero assegnato ad ogni partecipante, e non sarà possibile poter essere identificati.

I risultati potranno essere pubblicati su una rivista o presentati in una conferenza.

Se si desidera contattare una persona indipendente, che sa di questo progetto, ma non è coinvolta in esso, potrà contattare la Dottoressa Maria Fara DeCaro. Di seguito troverà i suoi contatti.

Se ha letto e compreso questo foglio informativo, se le sue domande hanno ricevuto risposta e vorrebbe partecipare allo studio, può leggere il modulo del consenso informato.

Contatti dei ricercatori

Nome del ricercatore: Clara Calia

Indirizzo: Dottoranda presso
Scuola di Arte, Scienze Sociali e Managment,
Divisione di Psicologia e Sociologia
Queen Margaret University, Edimburgo
Queen Margaret University Drive
Musselburgh
East Lothian EH21 6UU

E-mail: ccalia@qmu.ac.uk / 0131 474 0000

Contatti del consulente indipendente

Nome del consulente: Dottoressa Maria Fara DeCaro

Indirizzo: Professore in Psicologia,
Dipartimento di Neurooscienze e Organi di senso
Università degli Studi di Bari, Italia

E-mail / Telefono: maria.decaro@uniba.it/ 0039 080 5478578

Queen Margaret University

EDINBURGH

Consenso informato

Titolo del progetto: la memoria visuospaziale negli adulti e nei giovani

Dichiaro di aver letto e compreso il foglio informativo ed il modulo di consenso. Ho avuto l'opportunità di fare domande sulla mia partecipazione.

Ho capito che io non ho l'obbligo di prendere parte a questo studio.
Sono consapevole che ho il diritto di recedere dal presente studio in qualsiasi momento senza dare alcuna motivazione.
Sono consapevole che posso non rispondere alle domande senza dover dare alcuna spiegazione.

Accetto di partecipare a questo studio.

Nome del partecipante:________________________
Firma del partecipante:________________________
Firma del ricercatore:_________________________
Data:____________

Contatti del ricercatore
Nome del ricercatore: Clara Calia
indirizzo e-mail: ccalia@qmu.ac.uk

Indirizzo: Clara Calia
School of Arts, Social Sciences and Management
Division of Psychology and Sociology
Queen Margaret University Edinburgh, EH21 6UU

EXPERIMENT 3

P NUM________ Sex______________ Education _________________

Age______________________ PPT date___________________________

Condition Single digit Span ____________________________

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EXPERIMENT 3

P NUM________ Sex______________ Education_________________

Age_______________________ PPT date___________________________

Condition: Typical Keypad Span ____________________________

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BACKGROUND TESTS

As in the previous study (see Appendix 2), a number of tests were administered, including the Mini Mental Status examination (MMSE) (Folstein et al., 1975), Raven's Coloured Progressive Matrices (RCPM) (Raven, 1988), Digit Span forward & backward test (Wechsler, 1997), Visual Patterns Test (VPT) (Della Sala et al., 1997) and Corsi Block Tapping test (Spinnler e Tognoni, 1987).

Patients with mild cognitive impairments (MCI) were also administered an extensive neuropsychological battery of tests in order to assess different cognitive functions, to track the progression of dementia and to assess the effectiveness of medications or other rehabilitative strategies.

Below there is the list of neuropsychological tests used to screen patients with Mild Cognitive Impairment in addition to those used for the study.

FAB – Frontal Assessment Battery

Dubois et al. (2000). The FAB: a frontal assessment battery at bedside. Neurology, 55; 1621-1626.

Prova	Istruzioni	Punteggio
Similarità (astrazione)	"Cosa accomuna, in cosa sono simili?" banana e arancia[1] tavolo e sedia tulipano, rosa e margherita	3 risposte corrette: 3 2 risposte corrette: 2 1 risposta corretta: 1 0 risposte corrette: 0
Fluenza verbale (flessibilità mentale)	"Dica il maggior numero di parole inizianti con la lettera S, tranne nomi di persona o di città".[2] Tempo max: 60 sec.	>9 parole: 3 6-9 parole: 2 3-5 parole: 1 <3 parole: 0
Prensione (indipendenza ambientale)	Esaminatore seduto di fronte al paziente: questi appoggia le mani sulle sue ginocchia, tenendo il palmo rivolto verso l'alto. L'esaminatore porta le mani vicino a quelle del paziente, toccando il palmo di entrambe. Se il paziente afferra le mani dell'esaminatore si ripete la prova dicendo "Da ora in poi non deve più prendere le mie mani".	paziente non afferra: 3 esita e chiede cosa fare: 2 afferra senza esitazione: 1 afferra anche in caso di divieto: 0
Sequenze motorie (programmazione)	"Guardi attentamente ciò che sto per fare" L'esaminatore esegue sul tavolo per tre volte con la mano sinistra la sequenza di Luria taglio-pugno-palmo. "Ora, con la mano destra, esegua lei le sequenze. Iniziamo assieme, poi vada avanti da solo". L'esaminatore esegue le sequenze tre volte assieme al paziente, quindi dice: "Adesso faccia da solo, la fermerò io"	6 serie consecutive da solo: 3 3-5 serie consecutive da solo: 2 3 serie consecutive con l'esam: 1 0 serie consecutive con l'esam: 0
Ordini conflittuali (sensibilità all'interferenza)	"Se io batto un colpo, lei ne batta due" Verificare la comprensione battendo per tre volte un solo colpo sul tavolo: 1-1-1. "Se io batto due colpi, lei ne batta uno solo" Verificare la comprensione battendo per tre volte due colpi: 2-2-2. "Bene, faccia sempre il contrario di ciò che faccio io" Sequenza dell'esaminatore : 1-1-2-1-2-2-2-1-1-2	0 errori: 3 1-2 errori: 2 >2 errori: 1 4 errori consecutivi: 0
Go-No go (controllo e inibizione)	"Se io batto un colpo, anche lei batta una volta" Verificare la comprensione battendo per tre volte un colpo: 1-1-1. "Se io batto due colpi, lei non deve battere" Verificare la comprensione battendo per tre volte due colpi: 2-2-2. "Bene, risponda solo al colpo unico" Sequenza dell'esaminatore : 1-1-2-1-2-2-2-1-1-2	0 errori: 3 1-2 errori: 2 >2 errori: 1 4 errori consecutivi: 0

[1] In caso di risposta errata dire "banana e arancia sono due...", ma attribuire comunque un punteggio di 0 anche se il soggetto risponde correttamente; non fornire alcun aiuto per gli item succesivi. Le tre risposte corrette sono: frutti, mobili, fiori.

[2] Se il paziente non pronuncia alcuna parola entro 5 sec. dire "ad esempio, serpente". Se non da risposta per altri 10 sec. stimolarlo dicendo "qualsiasi parola che inizi per S". Nel computo del punteggio non conteggiare cognomi, nomi propri di persona, ripetizioni o parole derivate (es. stupido-stupidaggine-stupidita-ecc.)

Punteggio	$P_{corretto}$	PE
______/18	______	______

TEST DI MEMORIA DI PROSA
(Babcock, 1930; Spinnler e Tognoni, 1987)

"Sei / dicembre/. La scorsa / settimana / un fiume / straripò / in una piccola / città / situata / a 20 km / da Torino/. L' acqua / invase / le strade / e le case/. Quattordici / persone / annegarono / e seicento / si ammalarono / a causa dell' umidità / e del freddo/. Nel tentativo di salvare / un ragazzo / un uomo / si ferì / le mani."

Differita:

"Sei / dicembre/. La scorsa / settimana / un fiume / straripò / in una piccola / città / situata / a 20 km / da Torino/. L' acqua / invase / le strade / e le case/. Quattordici / persone / annegarono / e seicento / si ammalarono / a causa dell' umidità / e del freddo/. Nel tentativo di salvare / un ragazzo / un uomo / si ferì / le mani.

Punteggio:
Solo se vengono riferiti gli eventi "straripamento","morti", "ammalati", "tentativo di salvataggio"si valorizzano anche i dettagli relativi:

"Straripamento"	**3**	**punti**
"Piccola città" e/o "Vicino a Torino"	0.3	punti
"La scorsa settimana" e/o "6 dicembre"	0.3	punti
"Morti"	**2**	**punti**
"Numero morti" (da 9 a 19)	0.2	punti
"Ammalati"	**1**	**punto**
"Numero ammalati" (da 500 a 700)	0.1	punti
"Tentativo di salvataggio"	**1**	**punto**
"Ferimento" e/o "ragazzo"	0.1	punti

DIGIT SPAN

2-4	3-6
5-8-2	6-9-4
6-4-3-9	7-2-8-6
4-2-7-3-1	7-5-8-3-6
6-1-9-4-7-3	3-9-2-4-8-6
5-9-1-7-4-2-8	4-1-7-9-3-8-6
5-8-1-9-2-6-4-7	3-8-2-9-5-1-7-4
2-7-5-8-6-2-5-8-4	7-1-3-9-4-2-5-6-8

Diretto: ________
Inverso: ________

FAS

F:

A:

S:

5

(A)	2	6	5	9	4	5	2	5	2	6
(B)	4	1	2	5	1	3	0	4	9	1
(I)	0	6	7	6	8	9	8	0	8	0
(II)	9	0	4	3	0	1	9	3	7	6
(III)	7	9	5	3	7	8	8	9	7	6
(IV)	7	3	7	6	8	5	8	5	3	2
(V)	5	2	3	1	2	3	1	7	2	8
(VI)	4	1	7	4	7	6	9	1	8	3
(VII)	2	7	4	2	6	2	9	4	5	0
(VIII)	4	3	4	0	4	3	0	2	8	2
(IX)	6	1	5	6	1	5	8	3	6	9
(X)	4	5	2	8	1	3	9	1	5	1
(XI)	7	9	7	5	0	7	3	4	0	8

2	6

(A)	2	6	5	9	4	5	2	5	2	6
(B)	4	1	2	5	1	3	0	4	9	1
(I)	0	6	7	6	8	9	8	0	8	0
(II)	9	0	4	3	0	1	9	3	7	6
(III)	7	9	5	3	7	8	8	9	7	6
(IV)	7	3	7	6	8	5	8	5	3	2
(V)	5	2	3	1	2	3	1	7	2	8
(VI)	4	1	7	4	7	6	9	1	8	3
(VII)	2	7	4	2	6	2	9	4	5	0
(VIII)	4	3	4	0	4	3	0	2	8	2
(IX)	6	1	5	6	1	5	8	3	6	9
(X)	4	5	2	8	1	3	9	1	5	1
(XI)	7	9	7	5	0	7	3	4	0	8

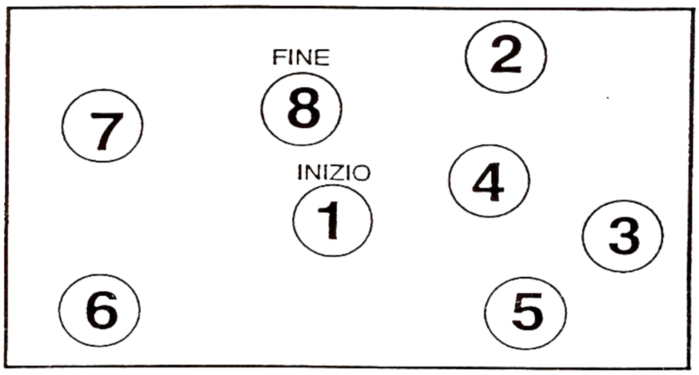
1	4	9

(A)	2	6	5	9	4	5	2	5	2	6
(B)	4	1	2	5	1	3	0	4	9	1
(I)	0	6	7	6	8	9	8	0	8	0
(II)	9	0	4	3	0	1	9	3	7	6
(III)	7	9	5	3	7	8	8	9	7	6
(IV)	7	3	7	6	8	5	8	5	3	2
(V)	5	2	3	1	2	3	1	7	2	8
(VI)	4	1	7	4	7	6	9	1	8	3
(VII)	2	7	4	2	6	2	9	4	5	0
(VIII)	4	3	4	0	4	3	0	2	8	2
(IX)	6	1	5	6	1	5	8	3	6	9
(X)	4	5	2	8	1	3	9	1	5	1
(XI)	7	9	7	5	0	7	3	4	0	8

TRAIL MAKING

PARTE A

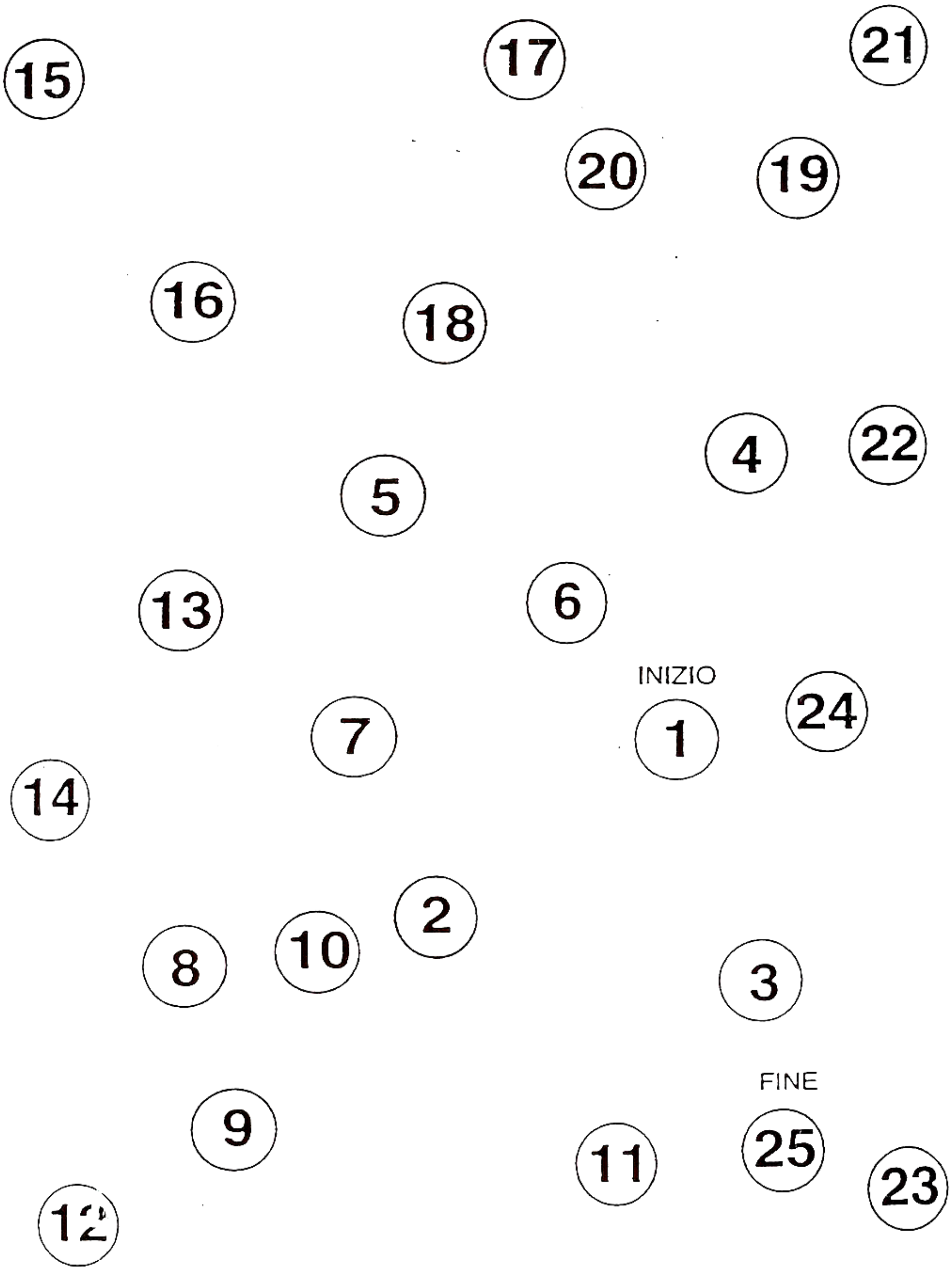
ESEMPIO



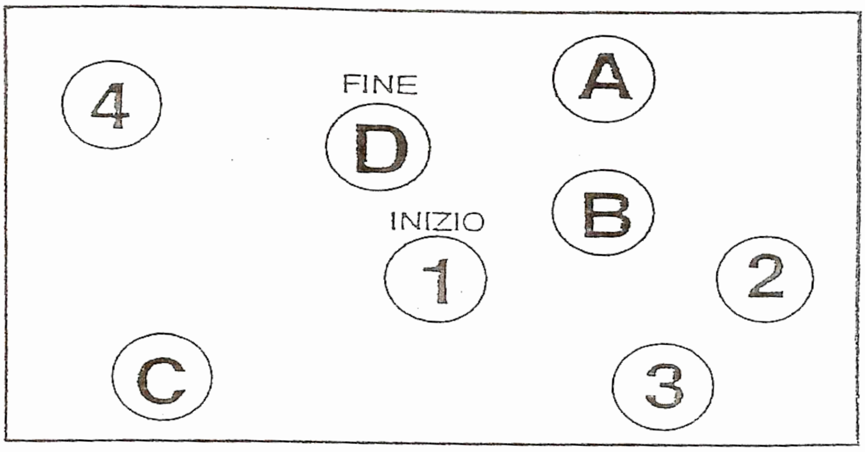
Nome : ....

Data : ....

Punti


15
17
21
20
19
16
18
4
22
5
13
6
INIZIO
24
1
7
14
2
10
8
3
FINE
9
11
25
23
12

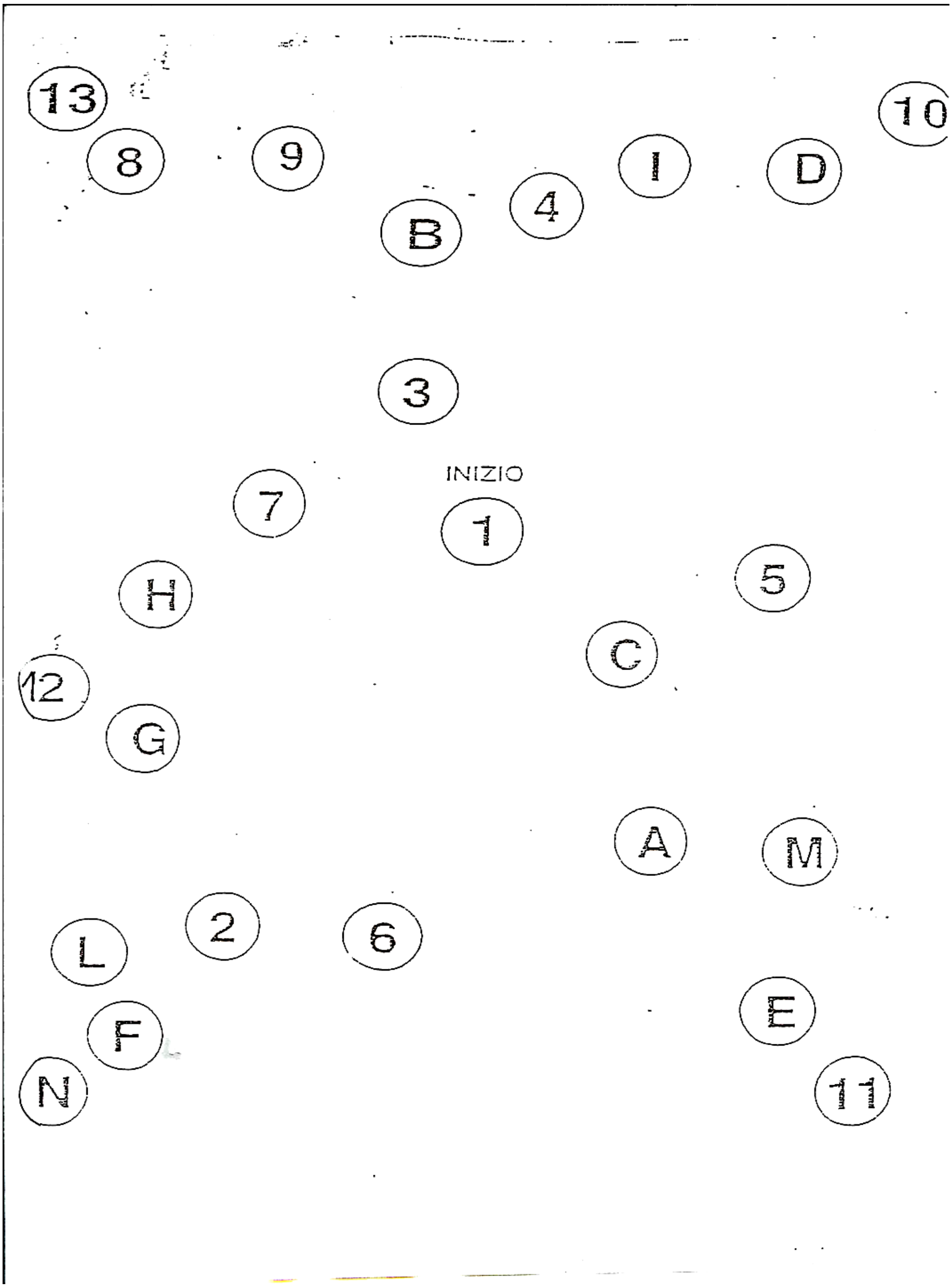
ESEMPIO



Nome : ....

Punti ....
•
•
•
....

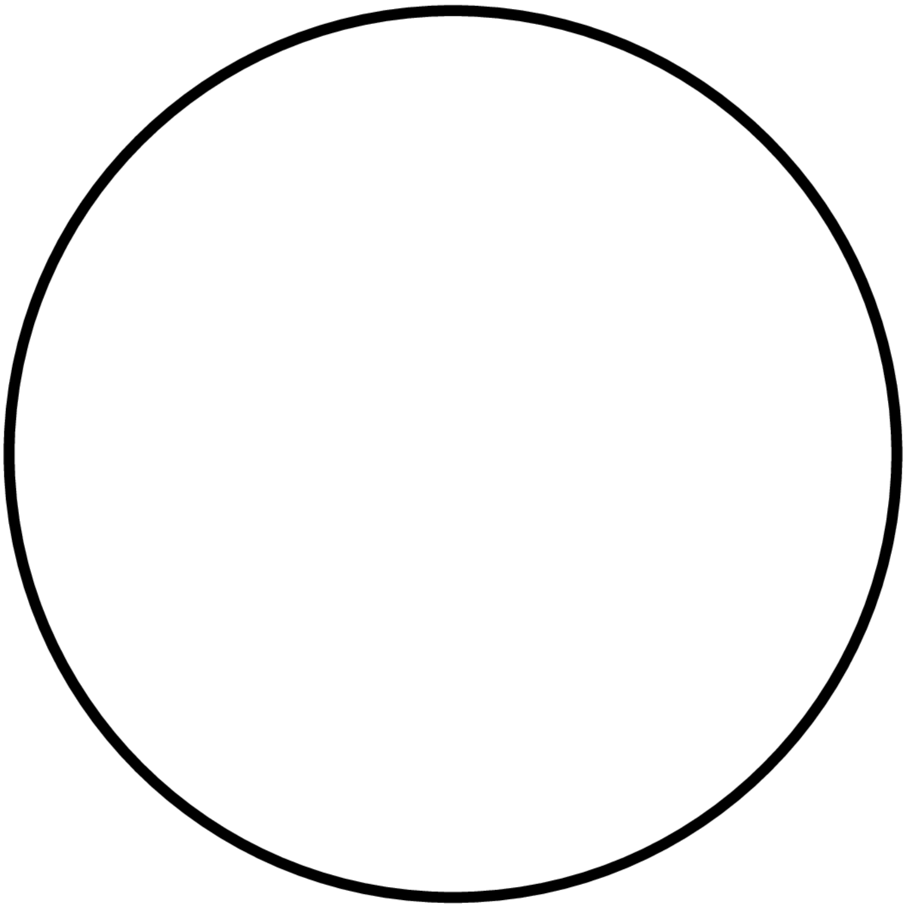
Data : ....


13
10
8
9
I
D
4
B
3
INIZIO
7
1
5
H
C
12
G
A
M
2
6
L
E
F
N
11

STROOP TEST- Example

Clock Drawing

Patient's Name: ______________________ Date: ______________________________



Geriatric Depression Scale (GDS)

		Ingr.	
		SI	NO
1	E' soddisfatto della sua vita?	0	1
2	Ha abbandonato molte delle sue attività e dei suoi interessi?	1	0
3	Ritiene che la sua vita sia vuota?	1	0
4	Si annoia spesso?	1	0
5	Ha speranza nel futuro?	0	1
6	E' tormentato da pensieri che non riesce a togliersi dalla testa?	1	0
7	E' di buon umore per la maggior parte del tempo?	0	1
8	Teme che le stia per capitare qualcosa di brutto?	1	0
9	Si sente felice per la maggior parte del tempo?	0	1
10	Si sente spesso indifesa?	1	0
11	Le capita spesso di essere irrequieto e nervoso?	1	0
12	Preferisce stare a casa, piuttosto che uscire a fare cose nuove?	1	0
13	Si preoccupa frequentemente per il futuro?	1	0
14	Pensa di avere più problemi di memoria rispetto alla maggior parte delle persone?	1	0
15	Pensa che sia bello stare al mondo, adesso?	0	1
16	Si sente spesso abbattuto e triste, adesso?	1	0
17	Trova che la sua condizione attuale sia quasi indegna di essere vissuta?	1	0
18	Si tormenta molto pensando al passato?	1	0
19	Trova che la vita sia molto eccitante?	0	1
20	Le risulta difficile iniziare ad occuparsi di nuovi progetti?	1	0
21	Si sente pieno di energia?	0	1
22	Pensa di essere in una situazione priva di speranza?	1	0
23	Pensa che la maggior parte delle persone sia in condizioni migliori della sua?	1	0
24	Le capita spesso di turbarsi per cose poco importanti?	1	0
25	Ha frequentemente voglia di piangere?	1	0
26	Ha difficoltà a concentrarsi?	1	0
27	Si alza con piacere la mattina?	0	1
28	Preferisce evitare gli incontri sociali?	1	0
29	Le riesce facile prendere delle decisioni?	0	1
30	Ha la mente lucida come prima?	0	1

Punteggio Totale __/30

ADL

Autonomia nelle attività della vita quotidiana

A **FARE IL BAGNO**

(Vasca, doccia, spugnature)

0. Fa il bagno da solo (entra ed esce dalla vasca da solo)
0. Ha bisogno di assistenza solamente nella pulizia di una parte del corpo (es. dorso)
1. Ha bisogno di assistenza per più di una parte del corpo

B **VESTIRSI**

(Prendere vestiti dall'armadio e/o cassetti, incluso biancheria intima, vestiti, uso delle allacciature e delle bretelle)

0. Prende i vestiti e si veste completamente senza bisogno di assistenza
0. Prende i vestiti e si veste senza bisogno di assistenza eccetto che per allacciare le scarpe
1. Ha bisogno di assistenza nel prendere i vestiti o nel vestirsi oppure rimane parzialmente completamente svestito

C **TOILLETTE**

(Andare nella stanza da bagno per la minzione e l'evacuazione, pulirsi, rivestirsi)

0. Va in bagno, si pulisce e si riveste senza bisogno di assistenza (può utilizzare mezzi di suppo come bastone, deambulatore o sedia a rotelle, può usare vaso da notte o comoda svuotandoli mattino)
1. Ha bisogno di assistenza nell'andare in bagno o nel pulirsi o nel rivestirsi o nell'uso del vaso notte o della comoda
1. Non si reca in bagno per l'evacuazione

D **SPOSTARSI**

0. Si sposta dentro e fuori dal letto ed in poltrona senza assistenza (eventualmente con canades deambulatore)
1. Compie questi trasferimenti se aiutato)
1. Allettato, non esce dal letto)

E **CONTINENZA DI FECI E URINE**

0. Controlla completamente feci e urine
1. Incidenti occasionali
1. Necessita di supervisione per il controllo di feci e urine, usa il catetere, è incontinente

F **ALIMENTAZIONE**

0. Senza assistenza
0. Assistenza solo per tagliare la carne e imburrare il pane
1. Richiede assistenza per portare il cibo alla bocca o viene nutrito parzialmente o completame per via parenterale

Tot. ______/6 funzioni perse

IADL

Autonomia nelle attività strumentali della vita quotidiana

A ABILITA' AD USARE IL TELEFONO

0. Usa il telefono di propria iniziativa: cerca il numero e lo compone
0. Compone solo pochi numeri ben conosciuti
0. Risponde al telefono, ma non compone numeri
1. E' incapace di usare il telefono

B FARE LA SPESA

0. Si prende cura della spesa e la fa in maniera autonoma
1. E' capace di effettuare solo piccoli acquisti
1. Ha bisogno di essere accompagnato per qualunque tipo di acquisto
1. E' completamente incapace di fare la spesa

C PREPARARE I PASTI

0. Pianifica i pasti, li prepara adeguatamente e li serve in maniera autonoma
1. Prepara i pasti solo se gli si forniscono tutti gli ingredienti
1. E' in grado solo di riscaldare cibi già pronti, oppure prepara i cibi in maniera non costante tanto da non riuscire a mantenere un'alimentazione adeguata
1. Ha bisogno di cibi già preparati e di esser servito

D CURA DELLA CASA

0. Riesce ad occuparsi della casa autonomamente o con occasionale aiuto per i lavori pesanti
0. Riesce ad effettuare i lavori domestici leggeri come lavare i piatti, rifare il letto, ecc..
0. Riesce ad effettuare lavori domestici leggeri, ma non è capace di mantenere un livello adeguato di pulizia
1. Ha bisogno di aiuto per tutte le pulizie della casa
1. E' completamente disinteressato a qualsiasi faccenda domestica

E FARE IL BUCATO

0. Lava tutta la propria biancheria
0. Lava solo i piccoli indumenti
1. Tutto il bucato deve essere fatto da altri

F SPOSTAMENTI FUORI CASA

0. Viaggia autonomamente, servendosi dei mezzi pubblici o della propria automobile
0. Fa uso di taxi, ma non è capace di usare i mezzi pubblici
0. Viaggia su mezzi pubblici solo se assistito o accompagnato
1. Viaggia in macchina o in taxi quando è assistito o accompagnato
1. Non può viaggiare affatto

G ASSUNZIONE DEI PROPRI FARMACI

0. E' capace di assumere correttamente le medicine
1. E' capace di assumere le medicine solo se in precedenza già preparate e separate
1. E' incapace di assumere da solo le medicine

H USO DEL PROPRIO DENARO

0. Provvede in modo autonomo alle proprie finanze (conti, fare assegni, pagare l'affitto e altre spese, andare in banca), controlla le proprie entrate
0. Provvede alle spese ed ai conti quotidiani, ma ha bisogno di aiuto per le operazioni maggiori (andare in banca, fare assegni, fare grosse spese, ecc..)
1. E' incapace di maneggiare il denaro

Tot. _______/8 funzioni perse